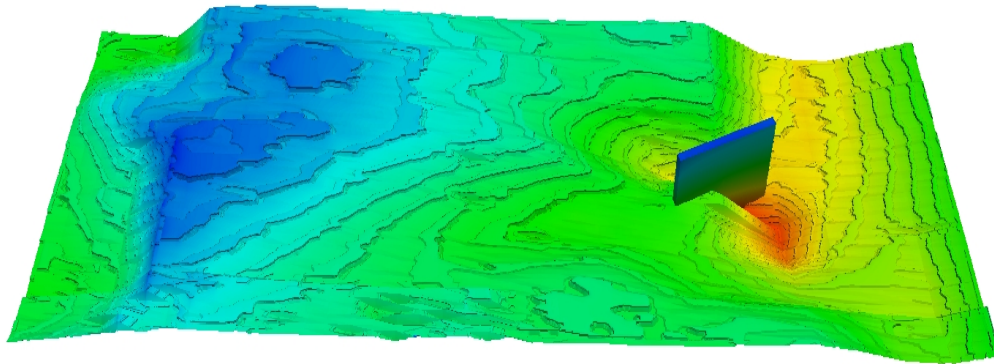


# SUBMERGED VANES TURBULENCE

## EXPERIMENTAL ANALYSIS

by

**Khaled M. A. Hamad Mohamed**



A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE DEGREE OF  
PhD. In Civil Engineering

Supervised by:

**Prof. Dr. Allen Bateman P.**



GRUP D'INVESTIGACIO EN MODELITZACIO DE CONQUES I  
TRANSPORT DE SEDIMENTS



Escola Tècnica Superior d'Enginyers  
de Camins, Canals i Ports de Barcelona

UNIVERSITAT POLITÈCNICA DE CATALUNYA

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Secretaría de  
Educación Superior,  
Ciencia, Tecnología e Innovación

*June 2015*

## **APPENDIX C.**

### **RESULTS – SUBMERGED VANES TURBULENCE STATISTICS**

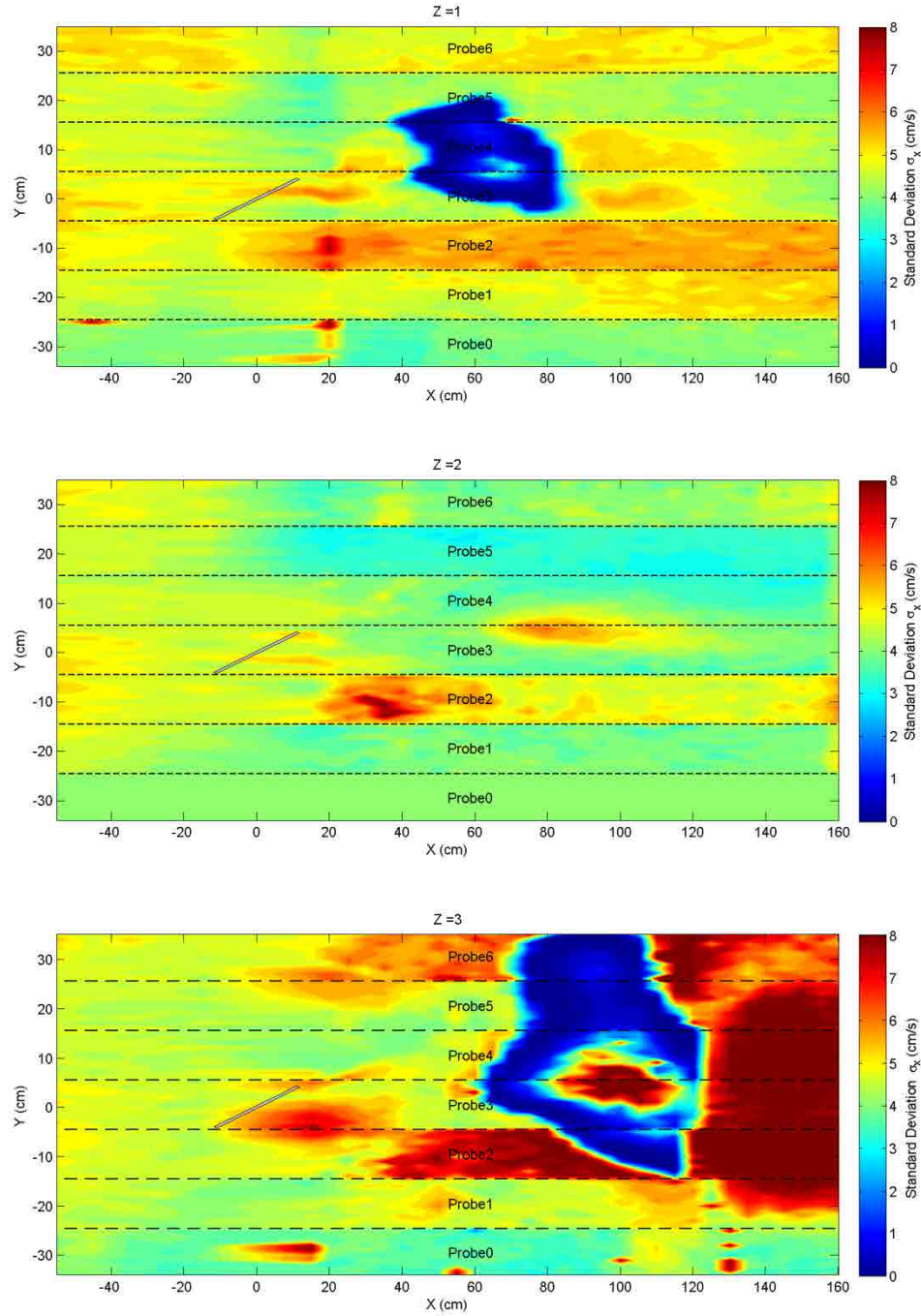


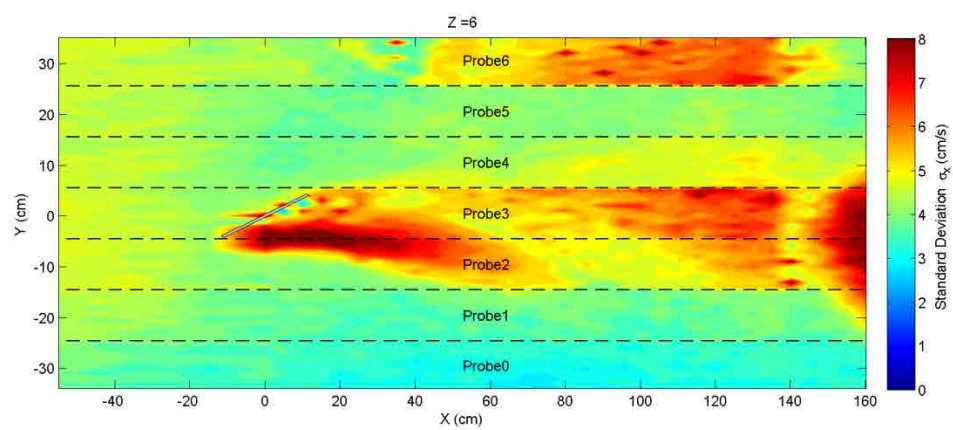
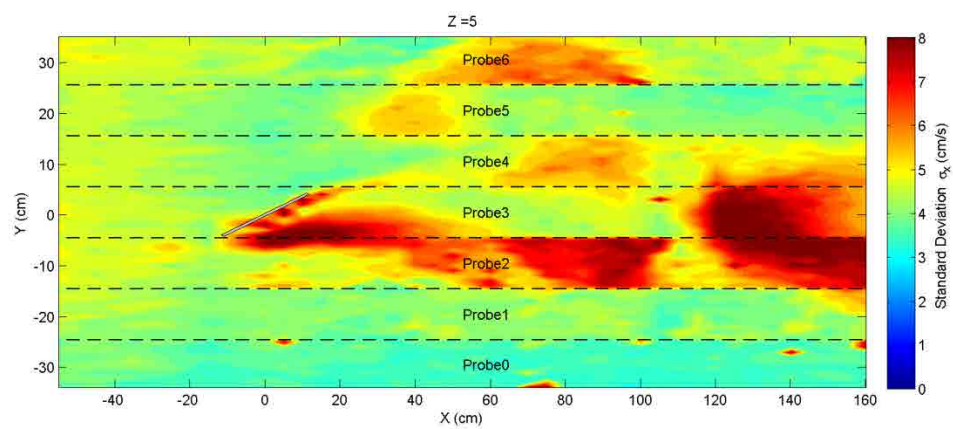
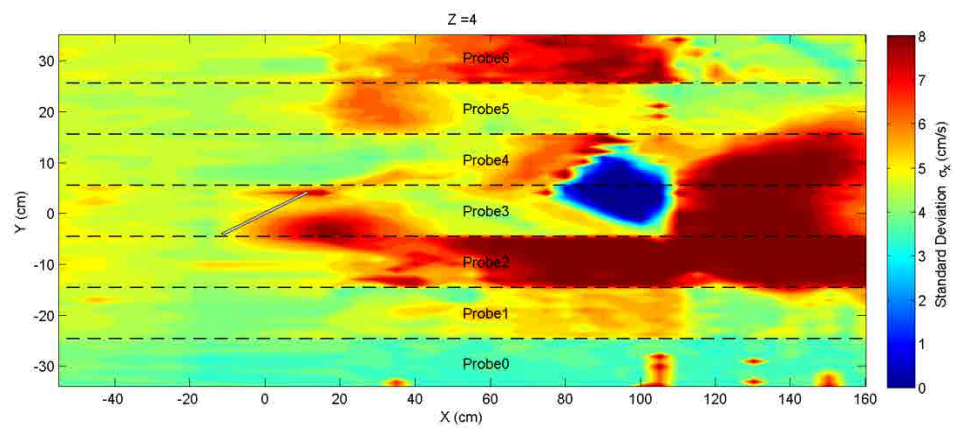
## Appendix C Results – Submerged Vanes Turbulence Statistics

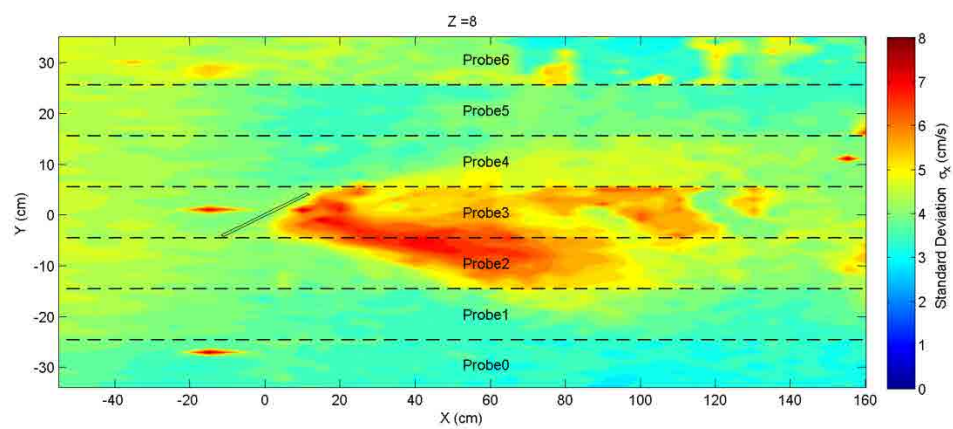
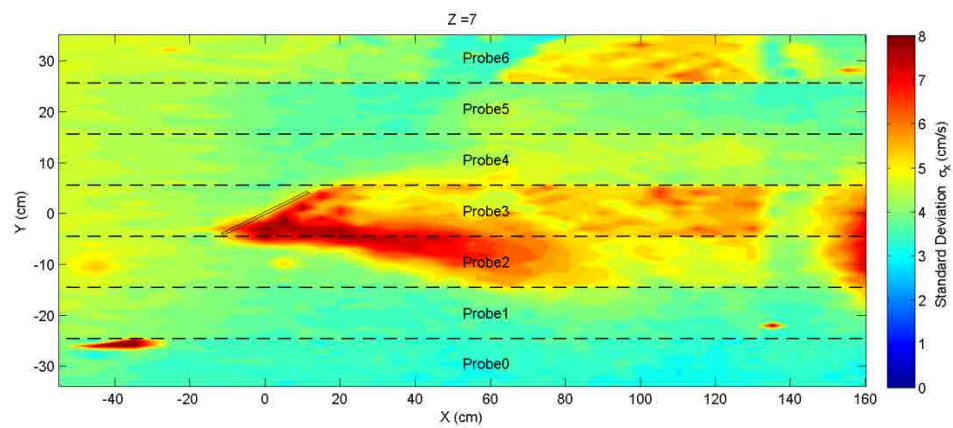
### C.1 Standard Deviation, Skewness and Kurtosis Factors

#### 1. Standard Deviation

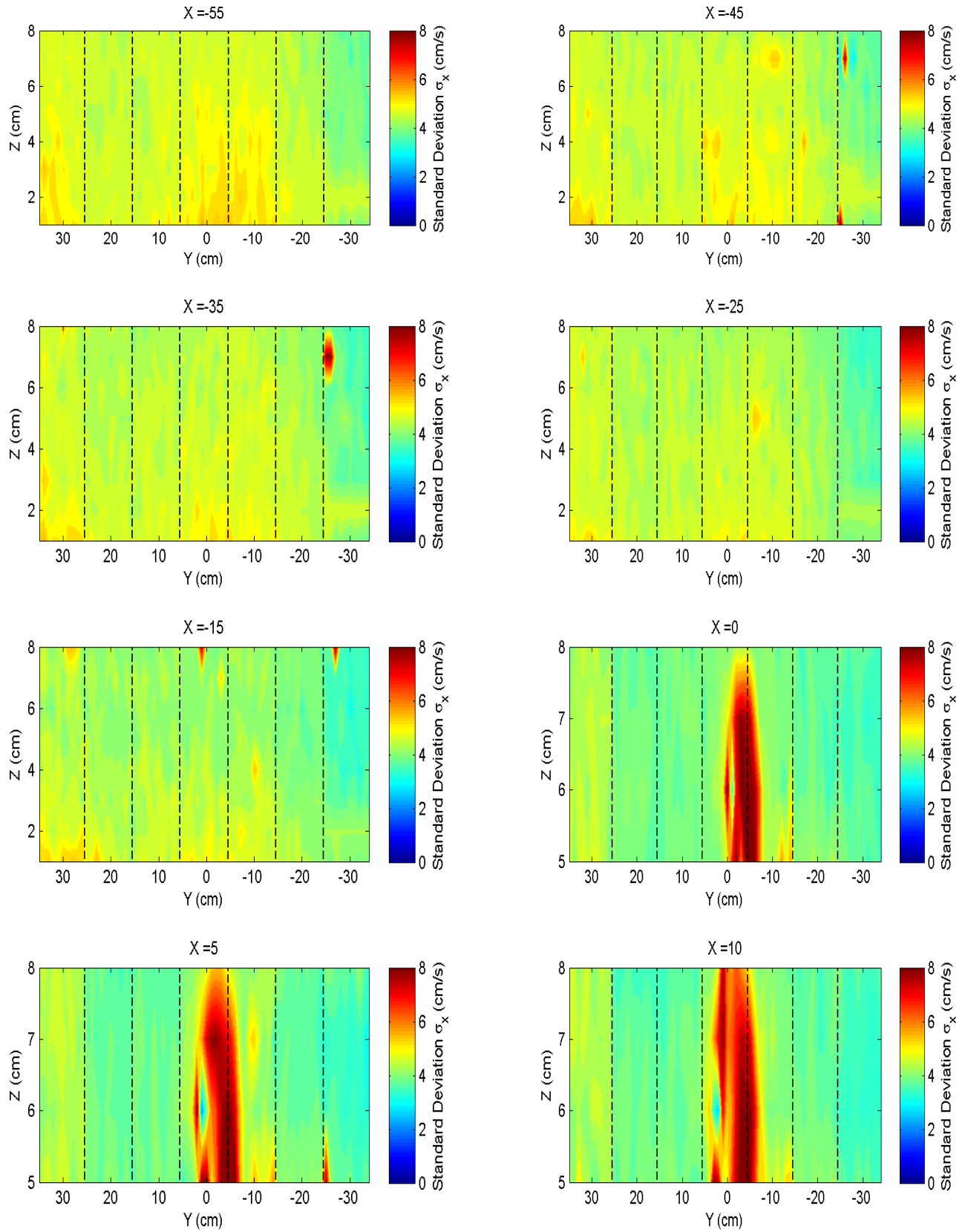
Standard Deviation  $\sigma_x$  in x and y-Directions



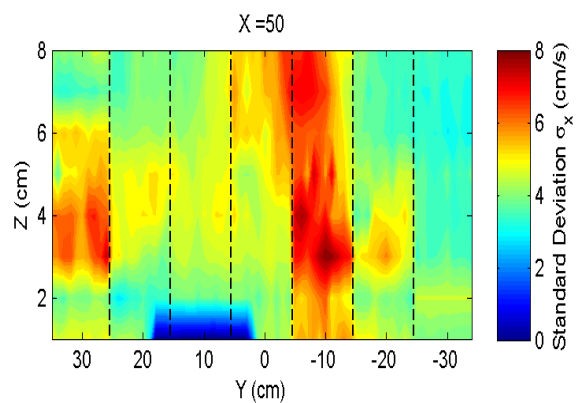
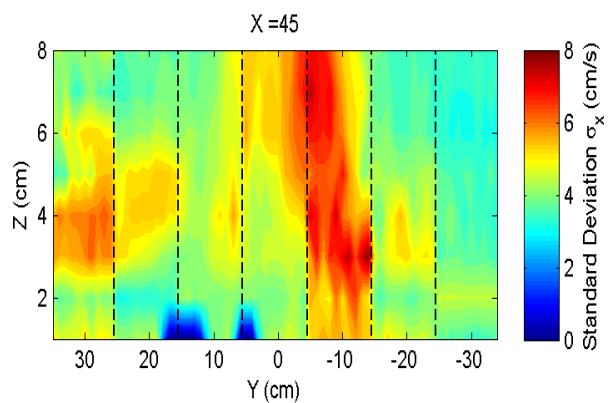
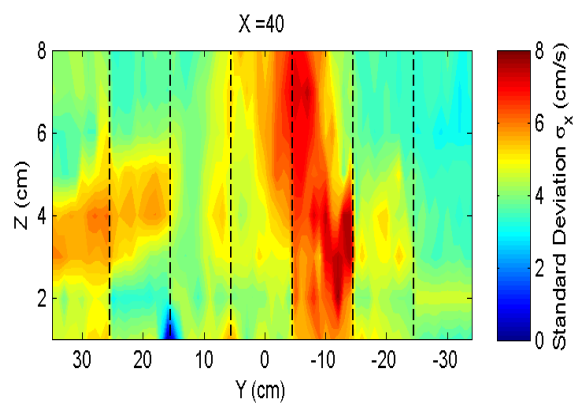
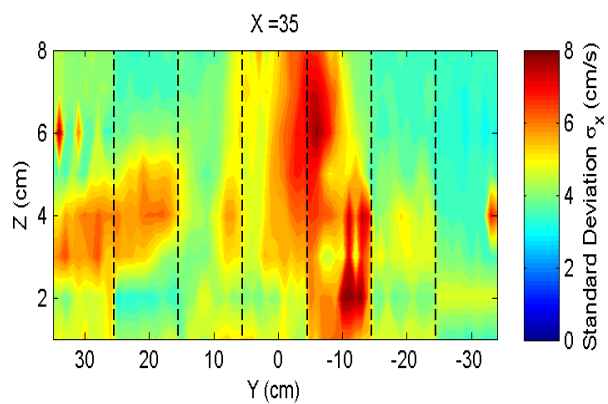
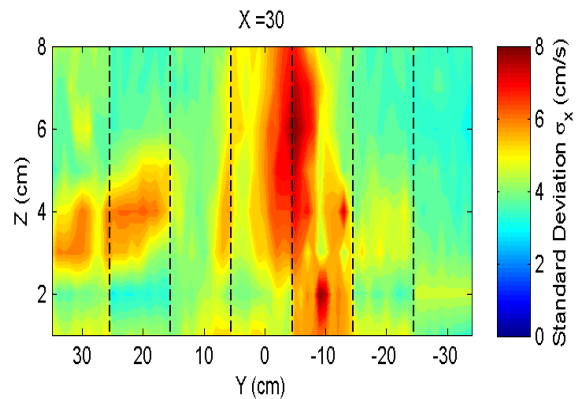
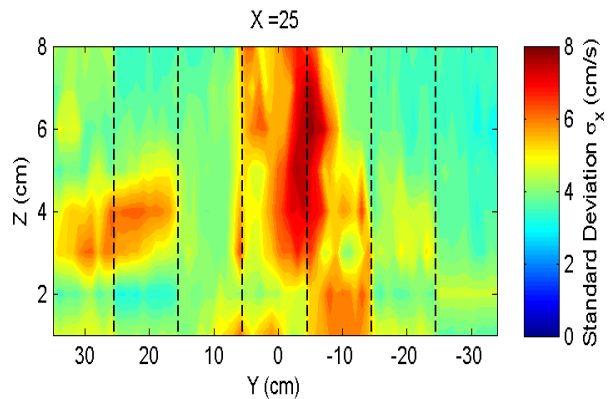
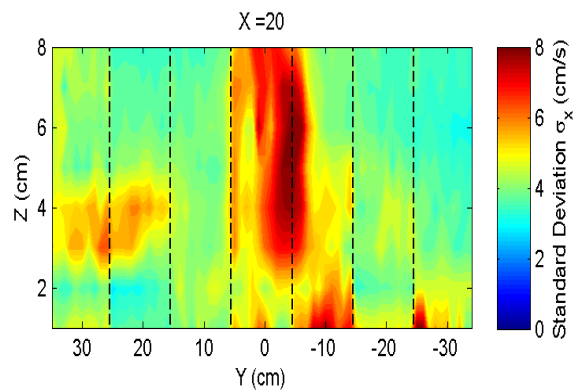
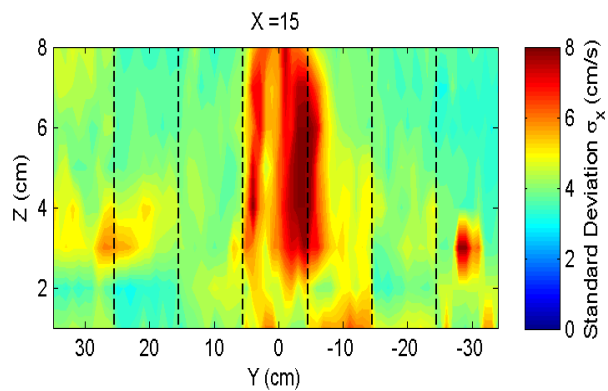


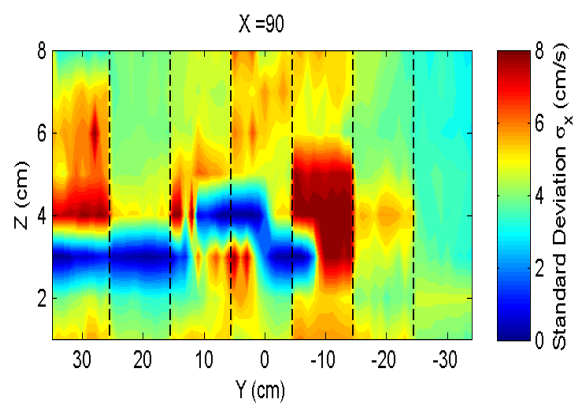
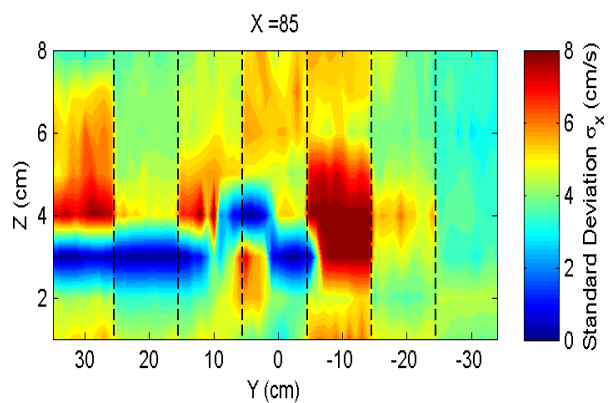
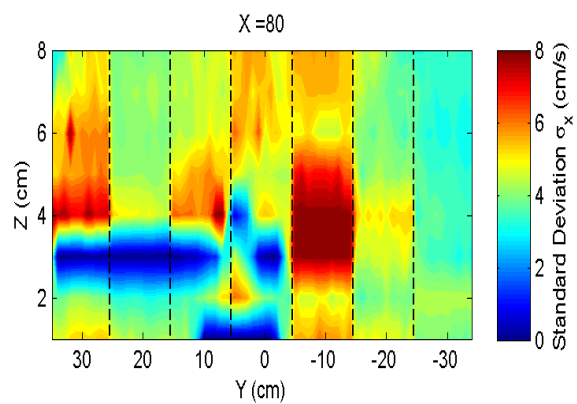
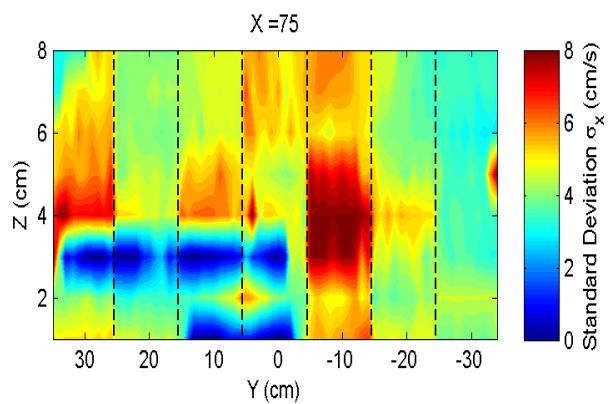
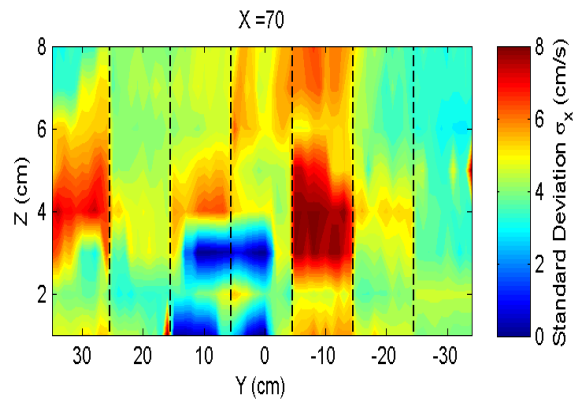
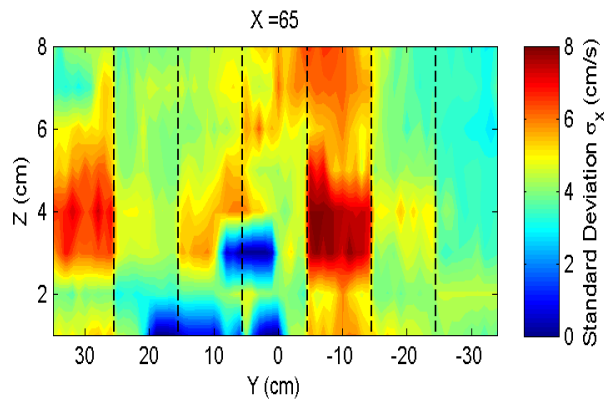
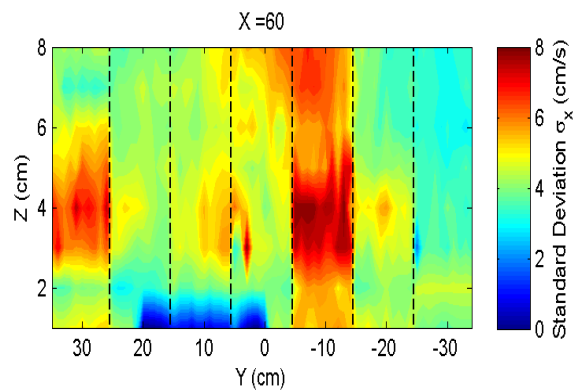
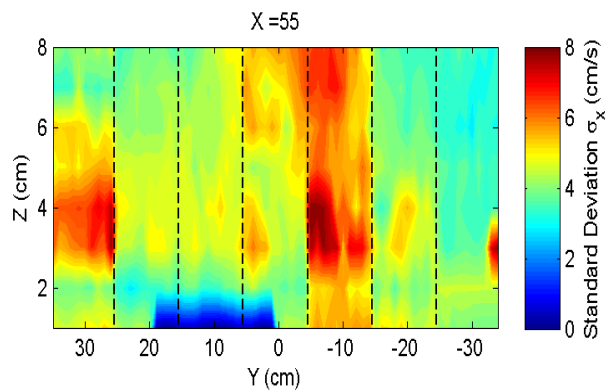


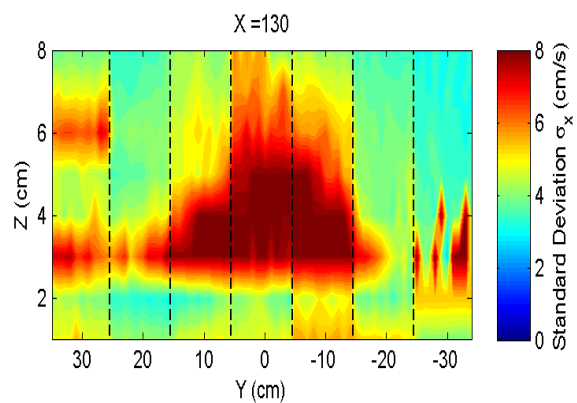
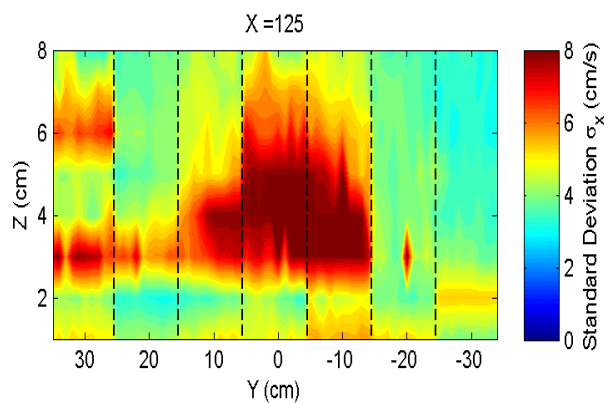
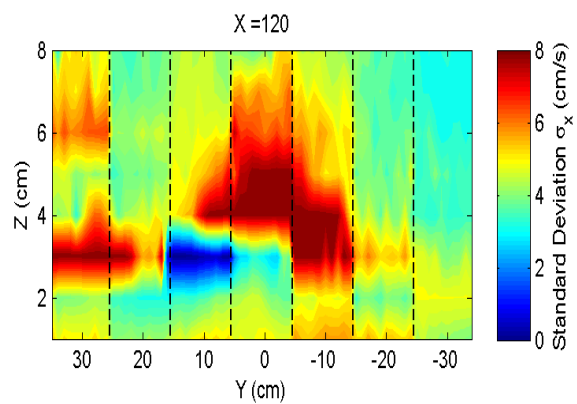
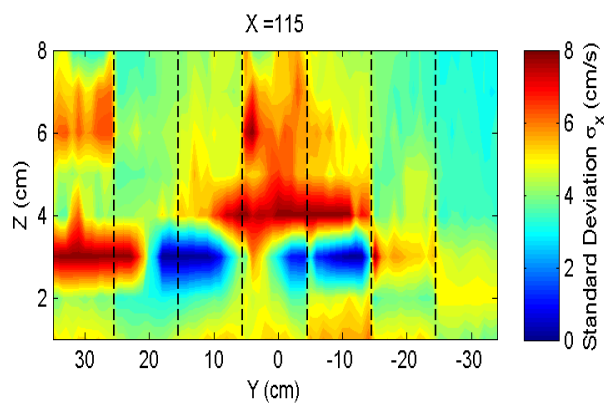
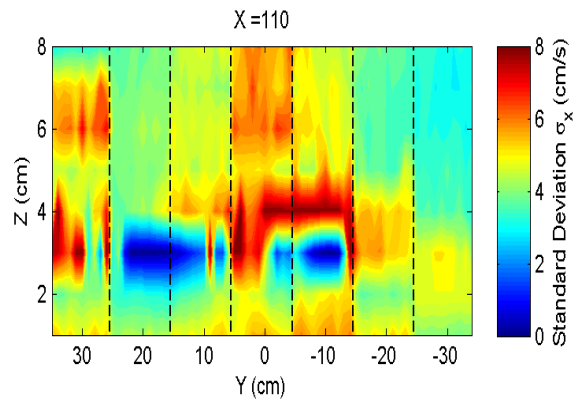
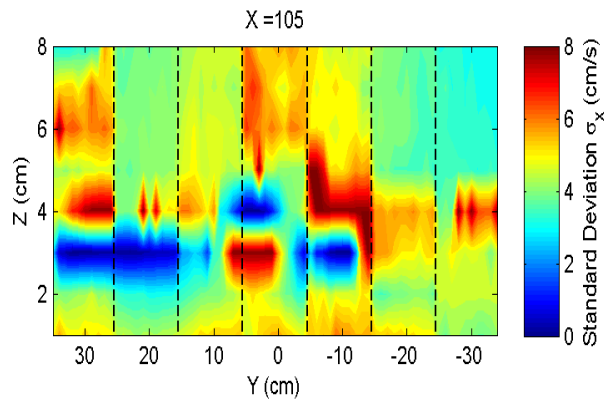
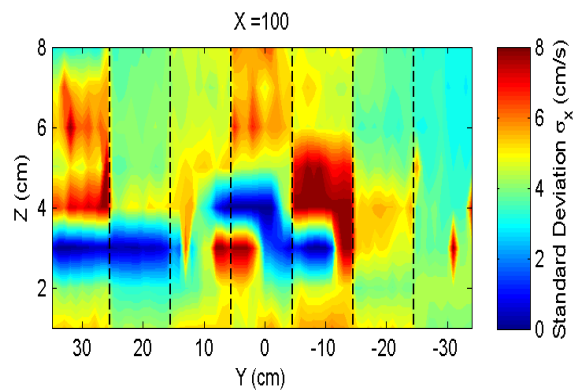
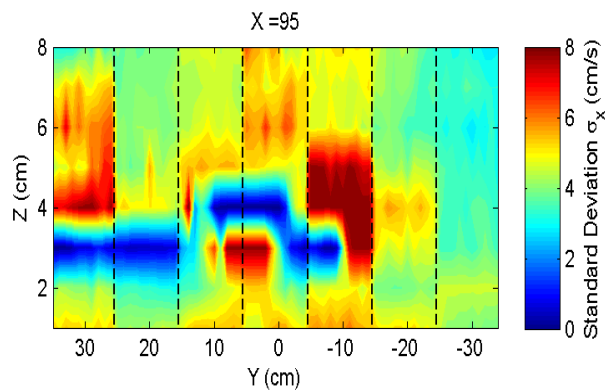
## Standard Deviation $\sigma_x$ in y and z-Directions

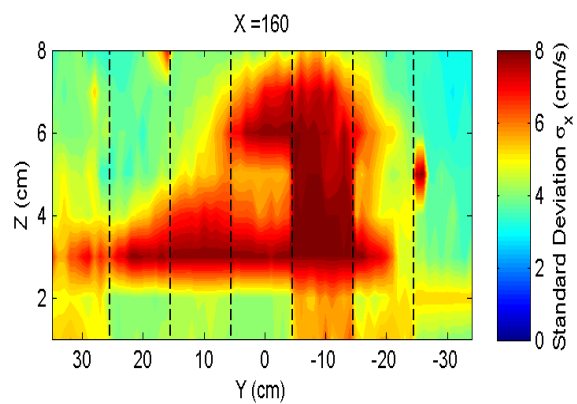
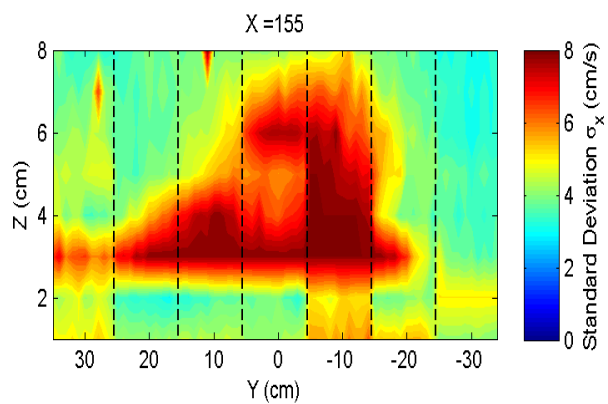
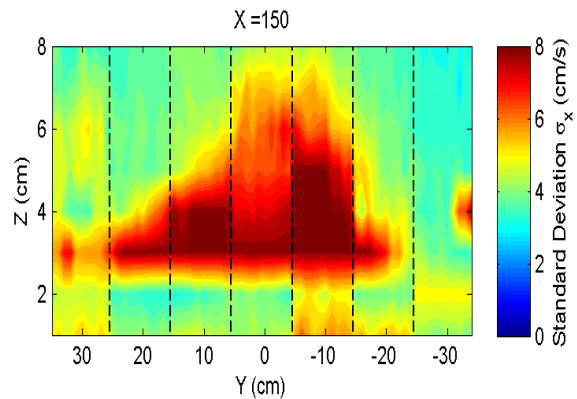
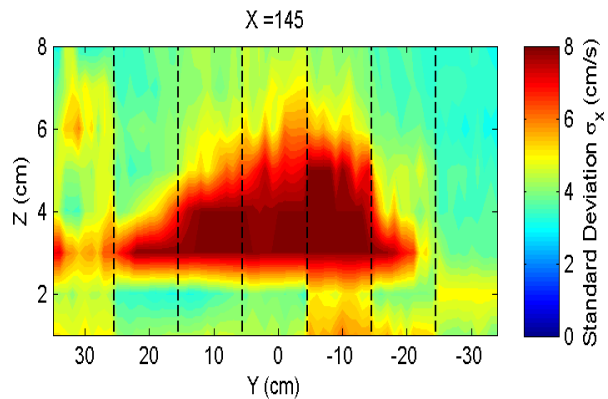
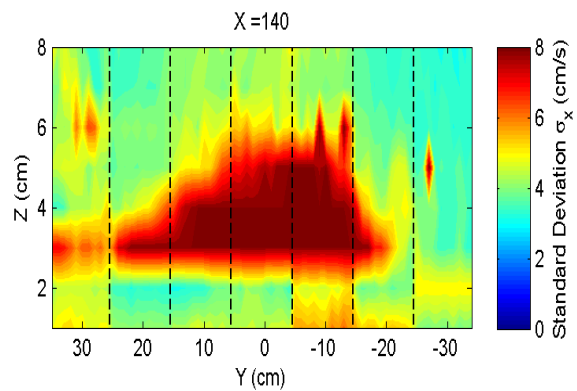
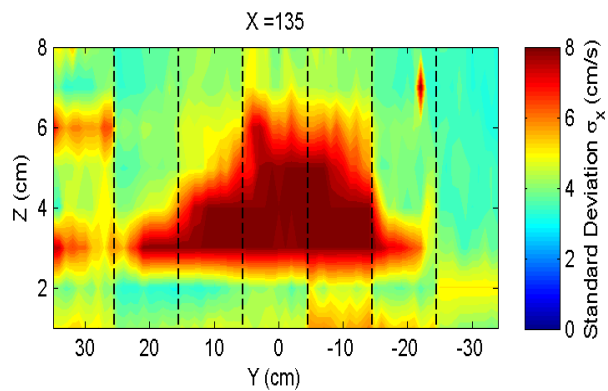






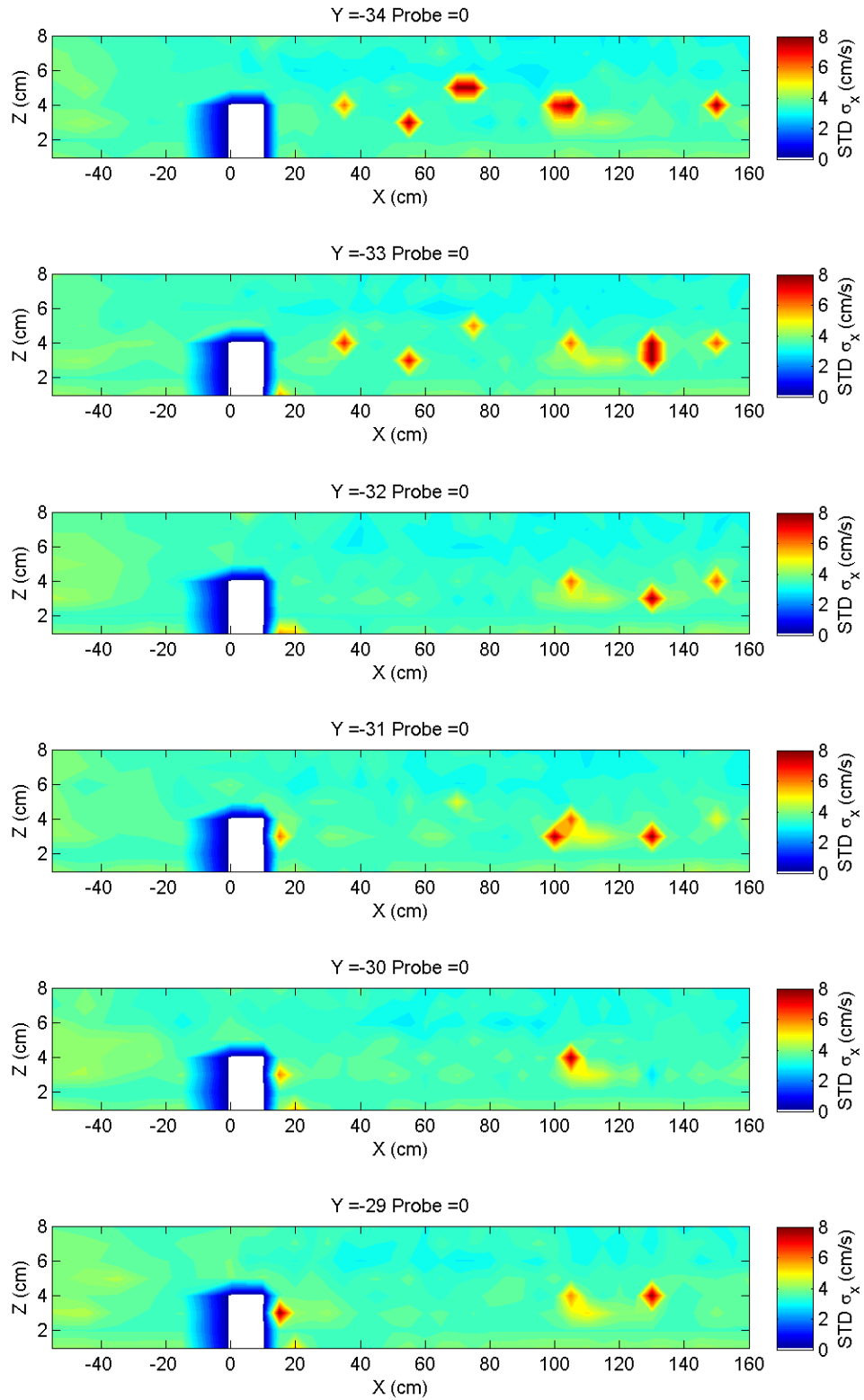


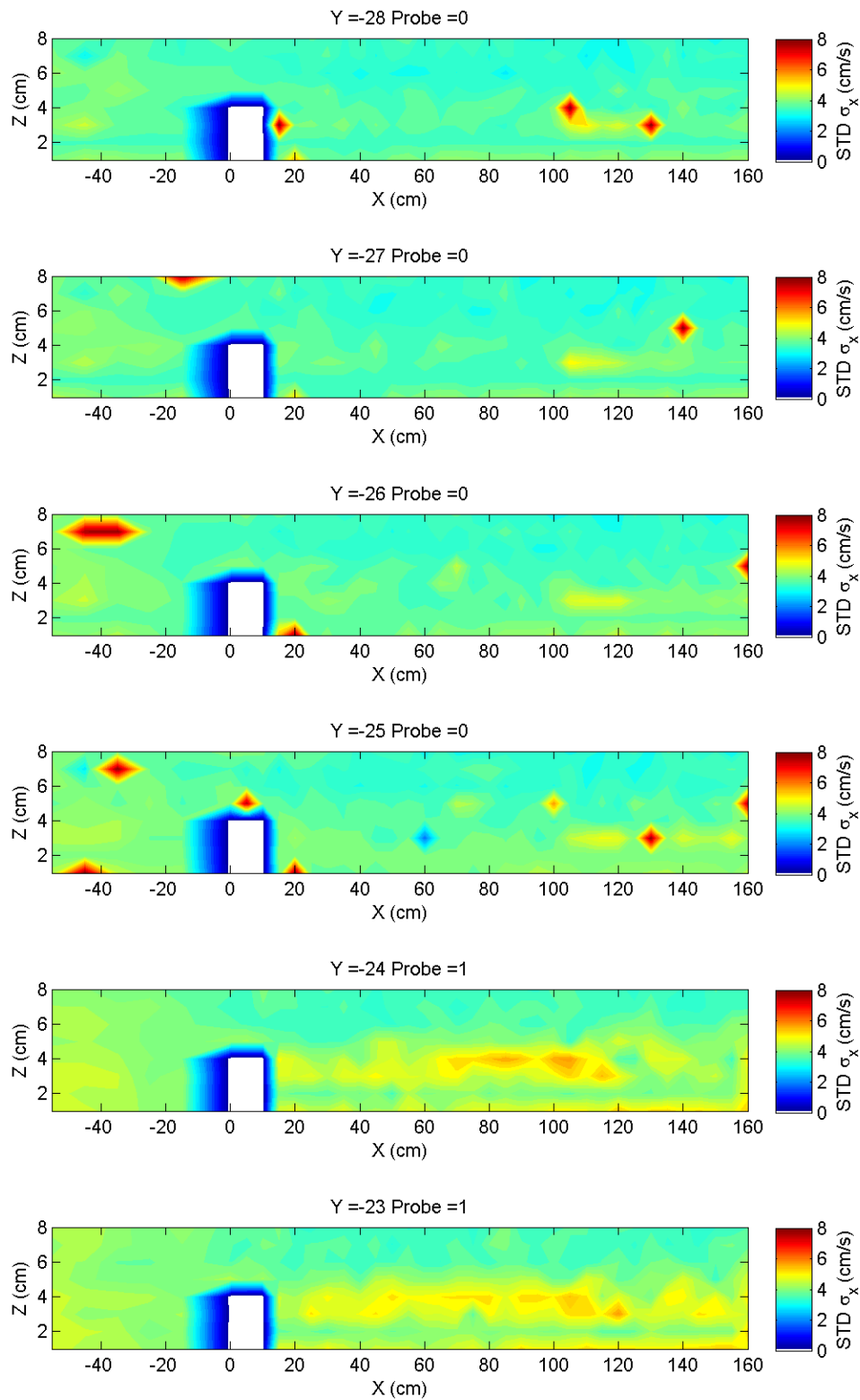


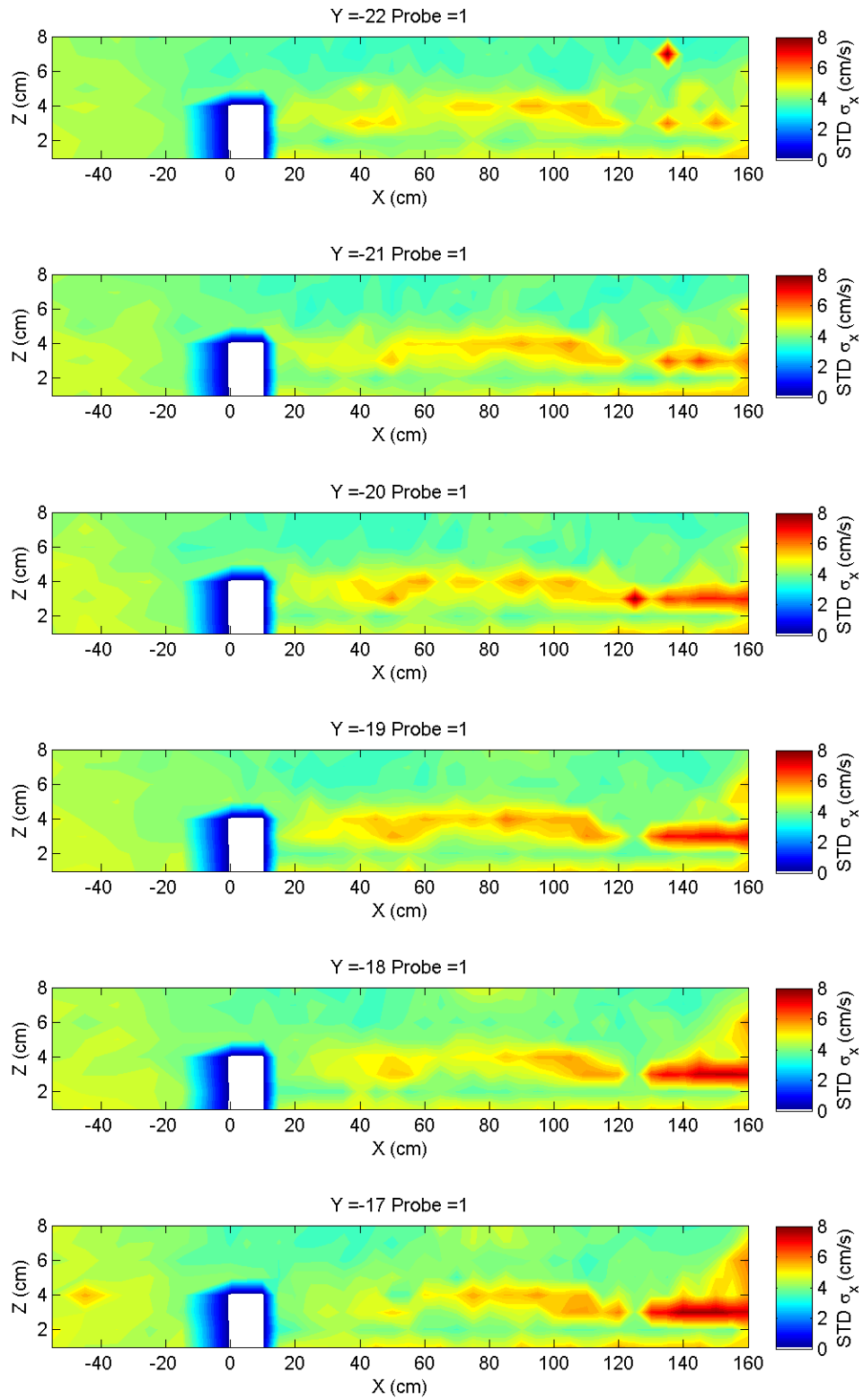


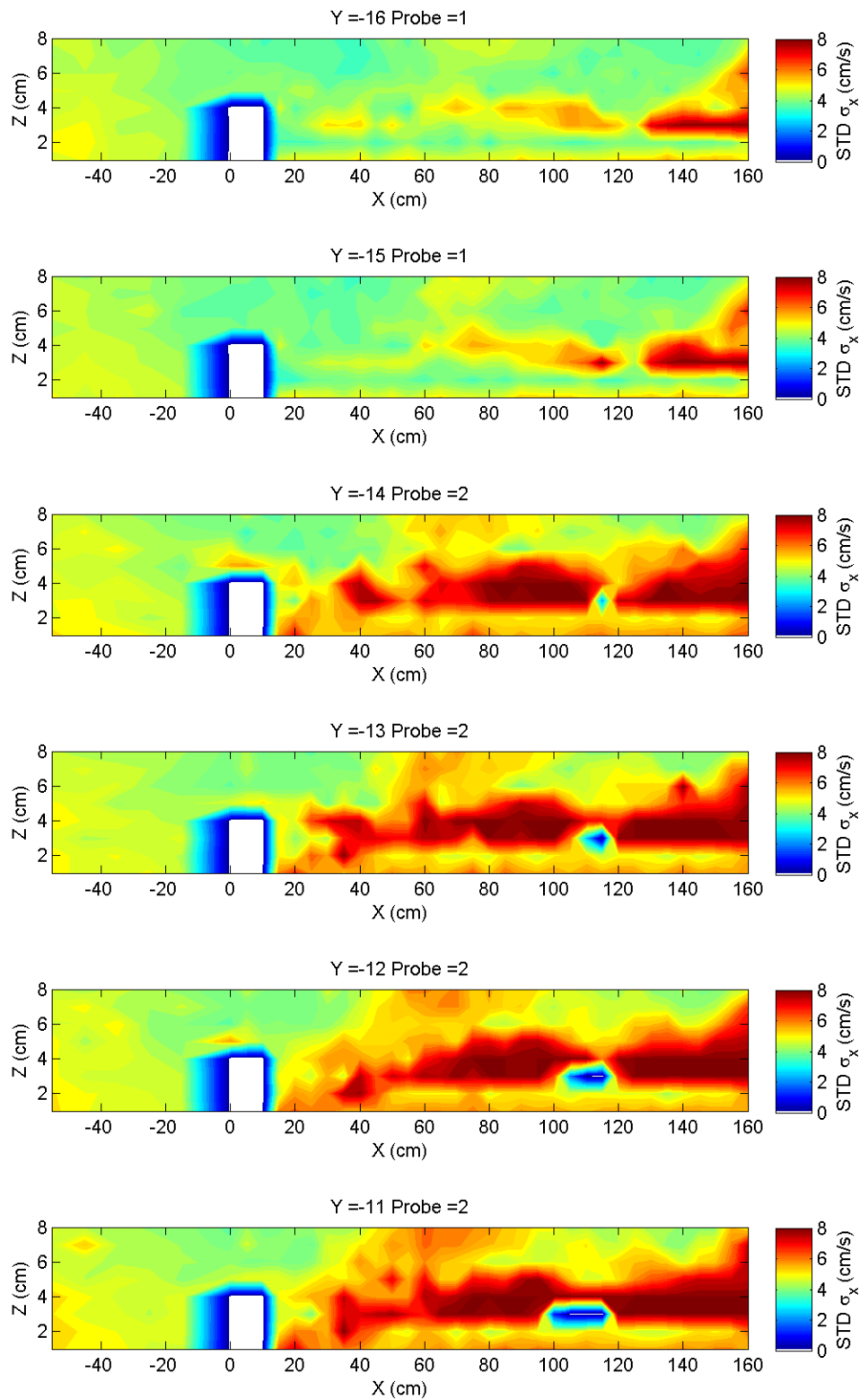


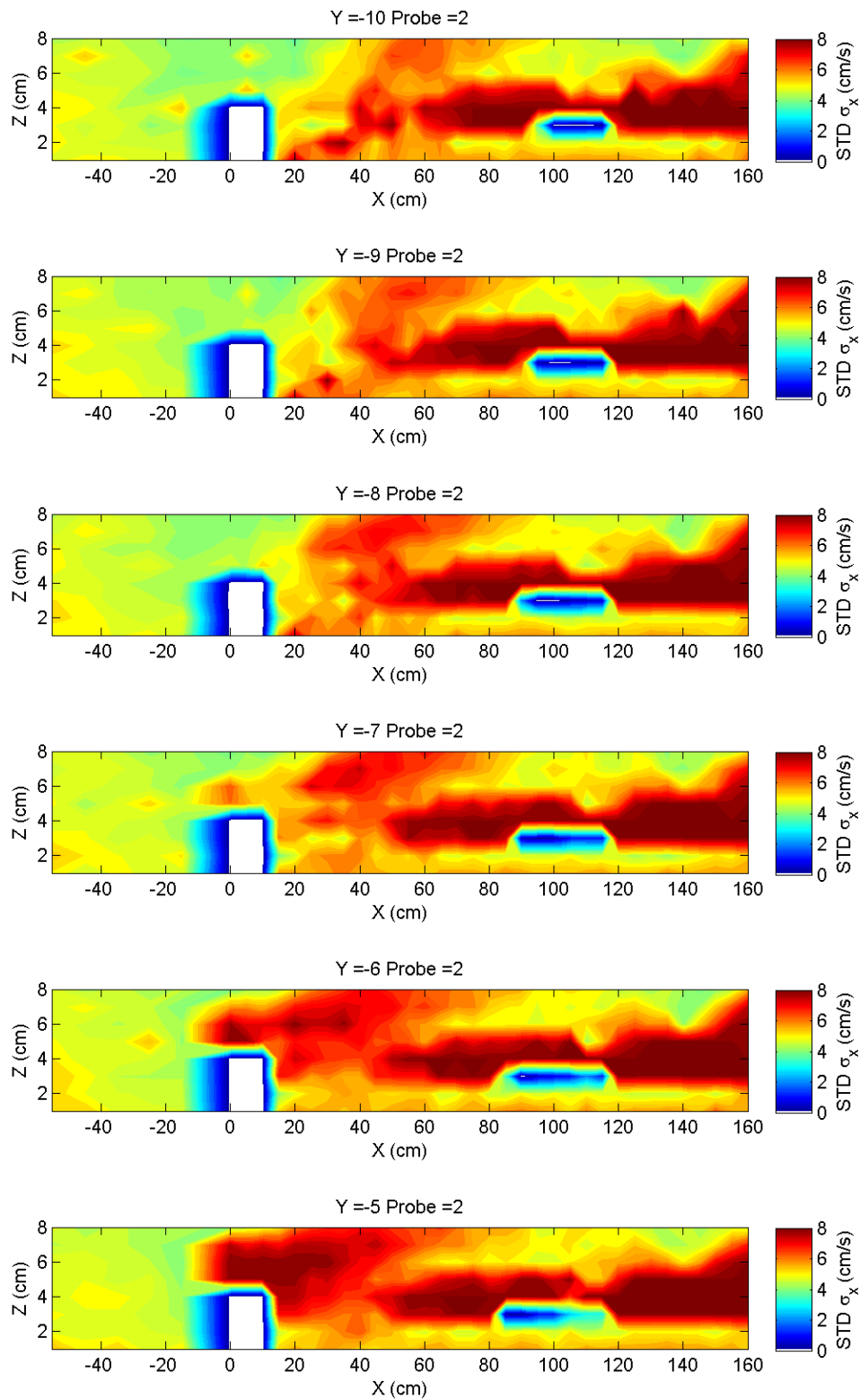
## Standard Deviation $\sigma_x$ in x and z-Directions



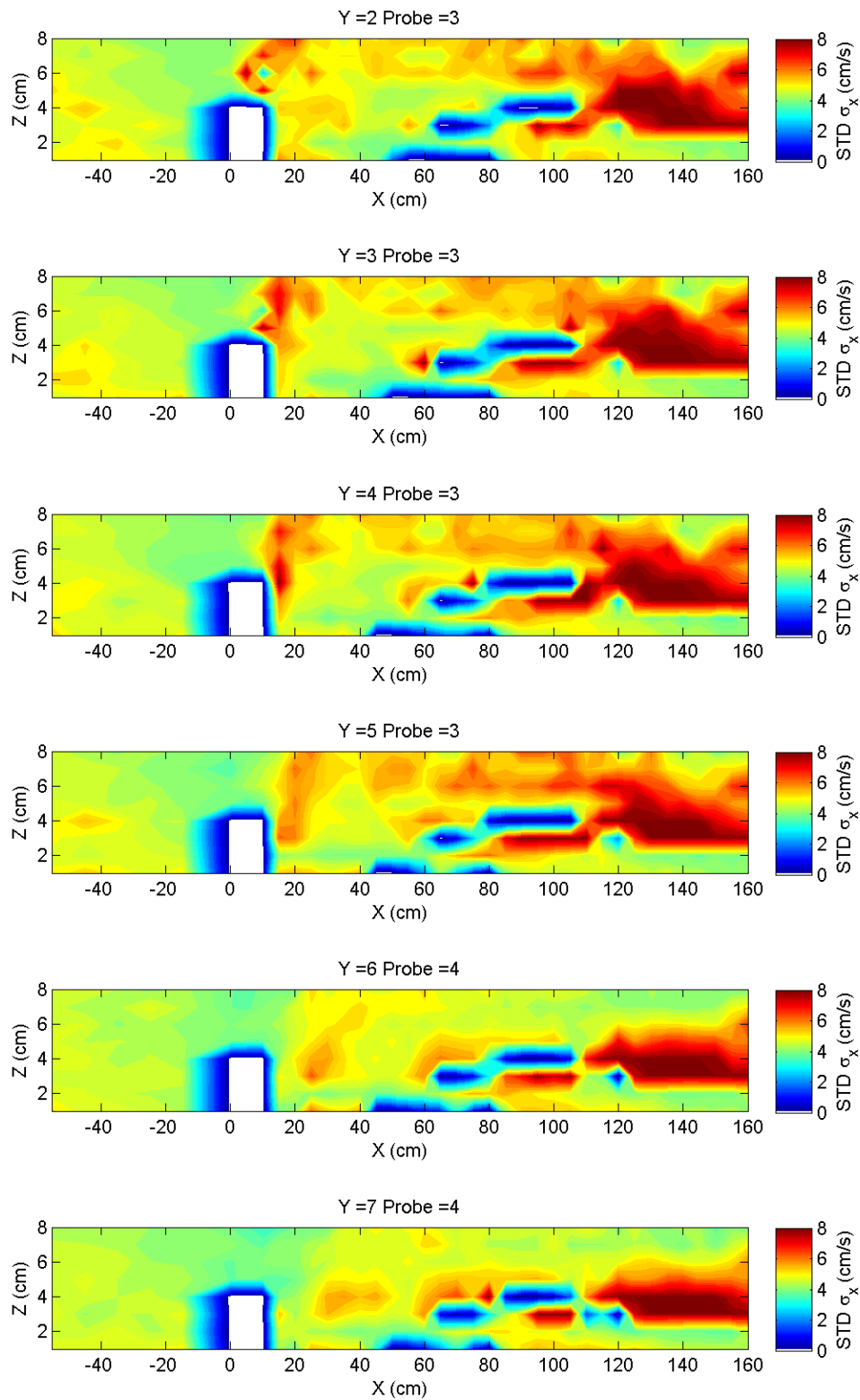


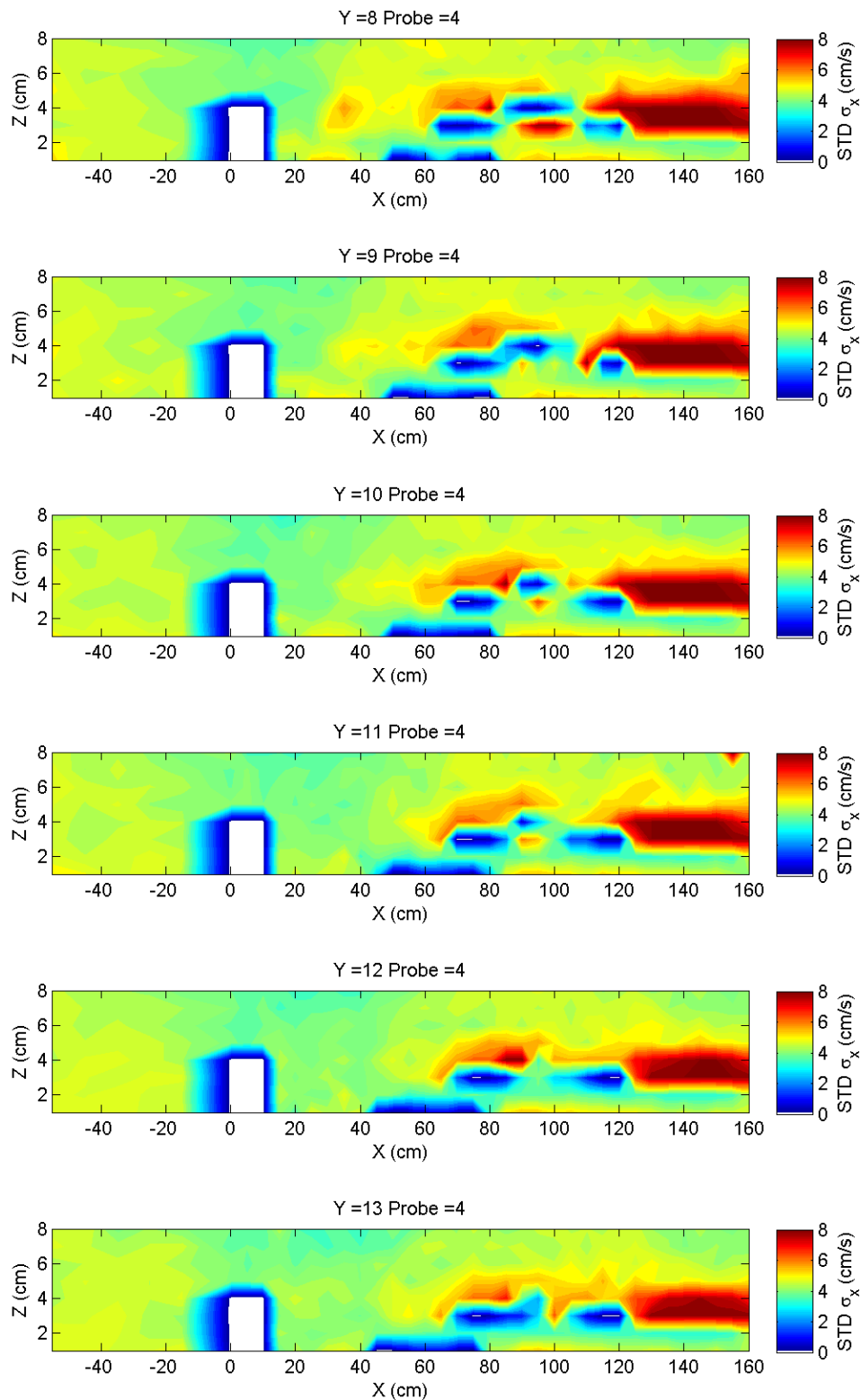




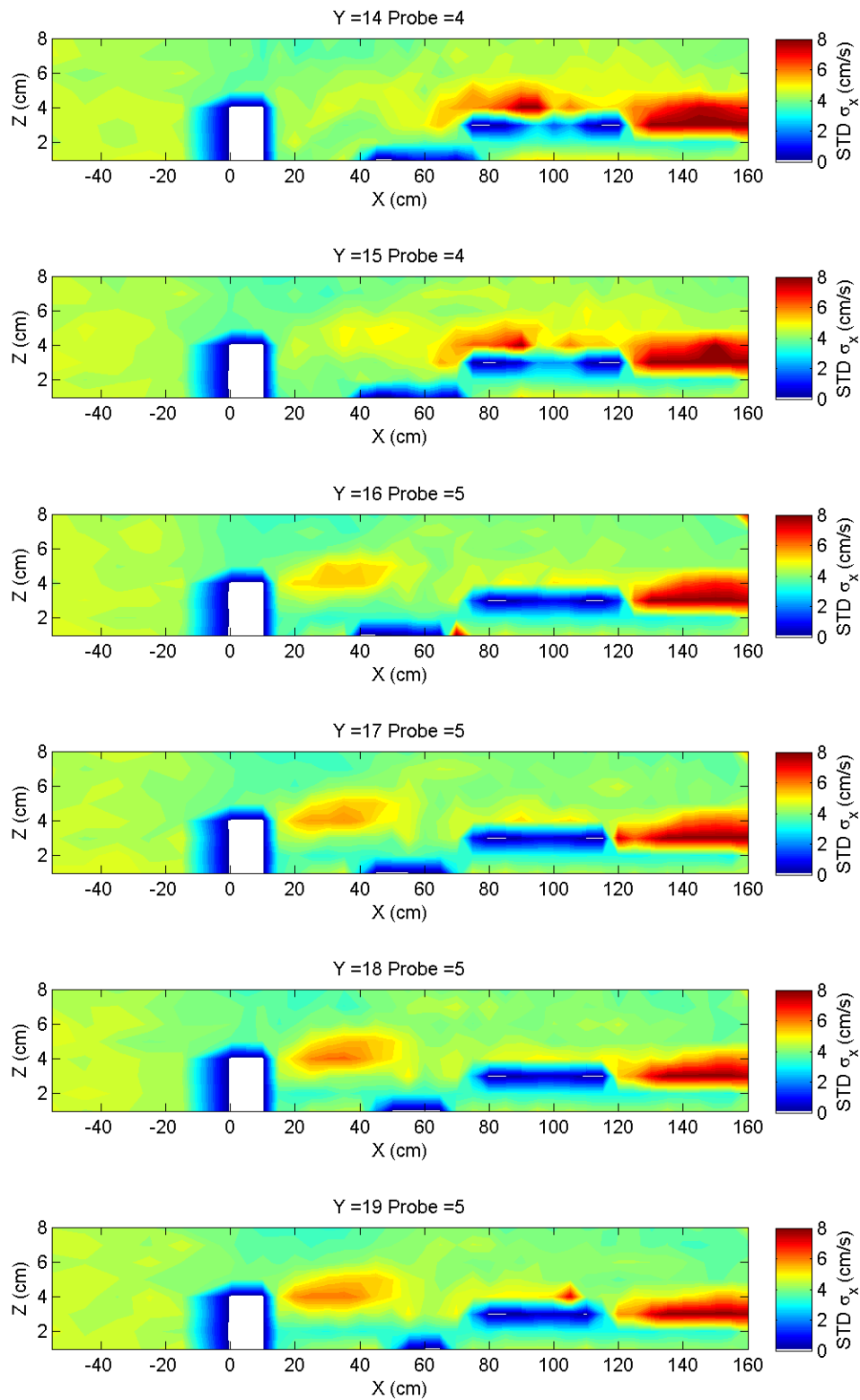


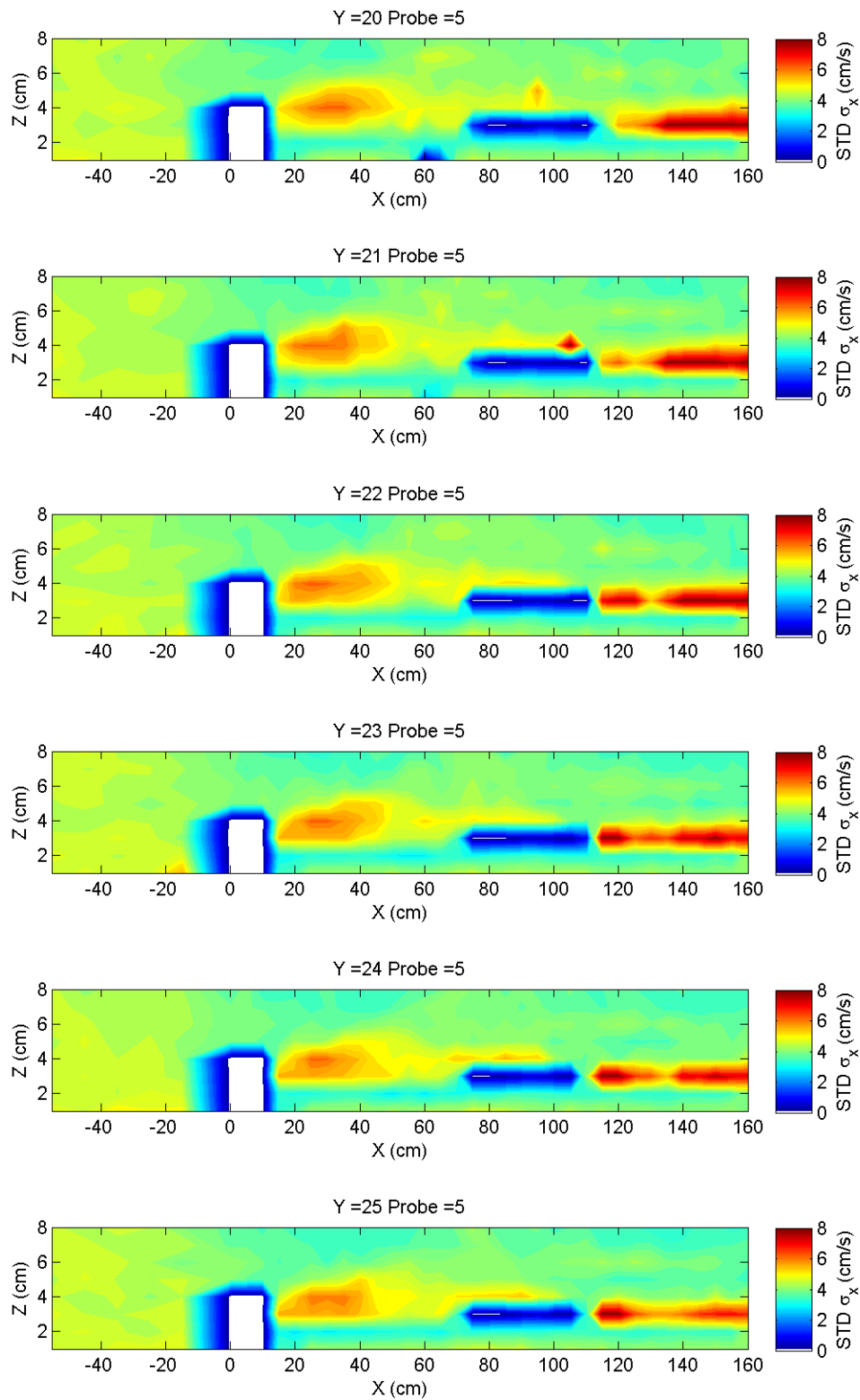


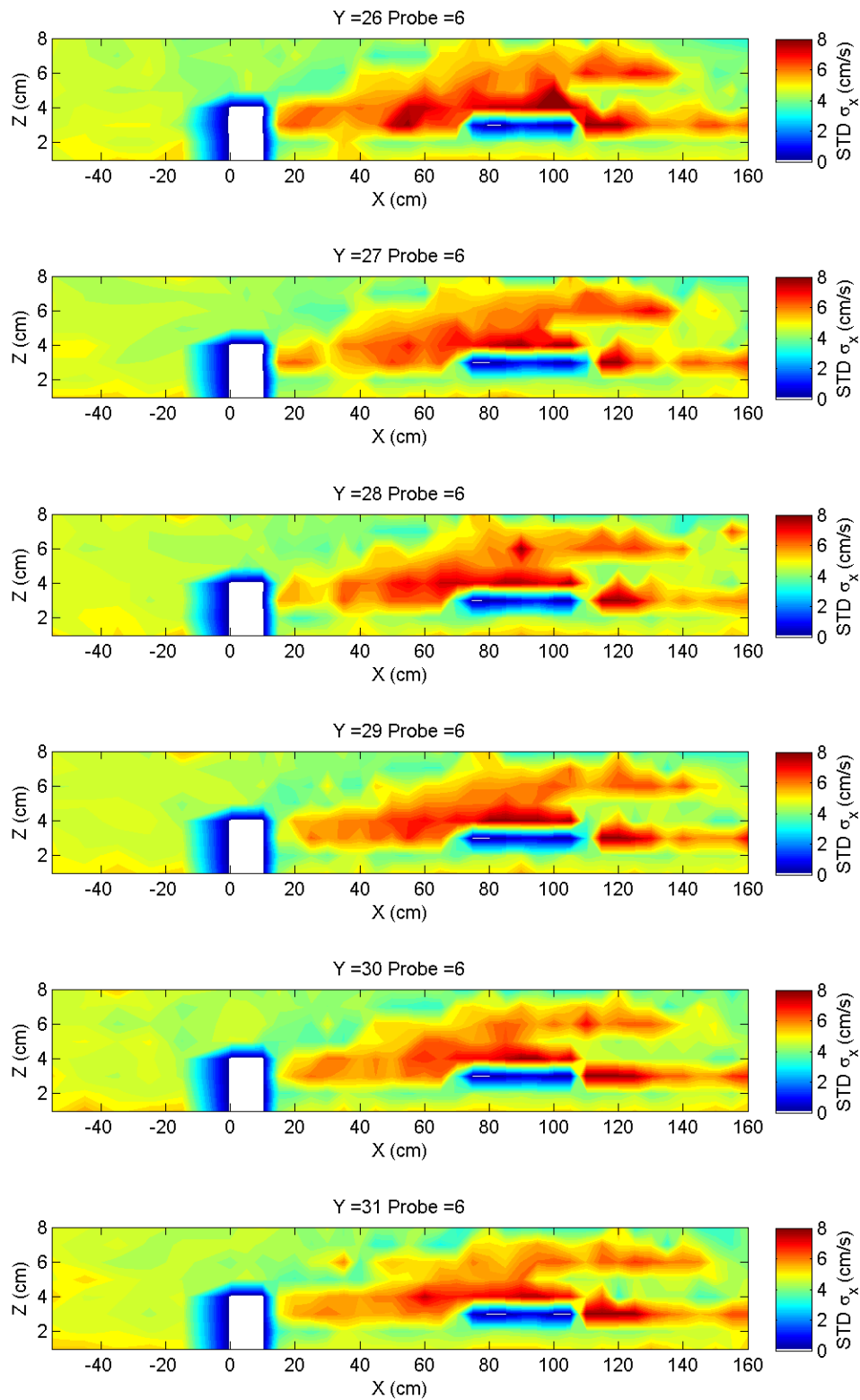


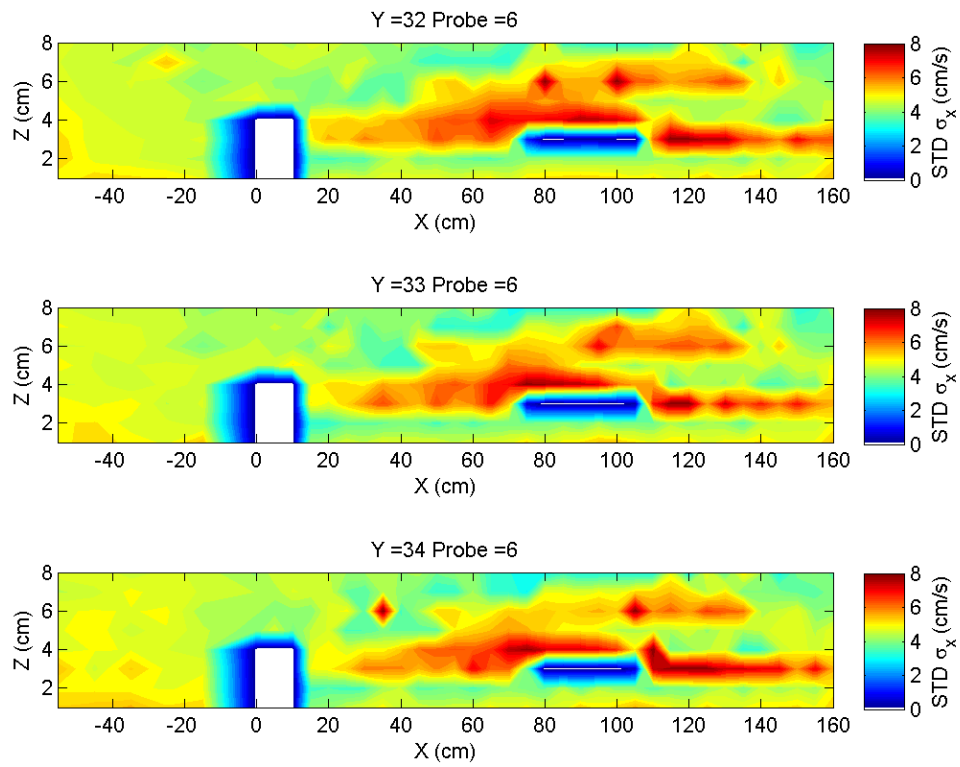




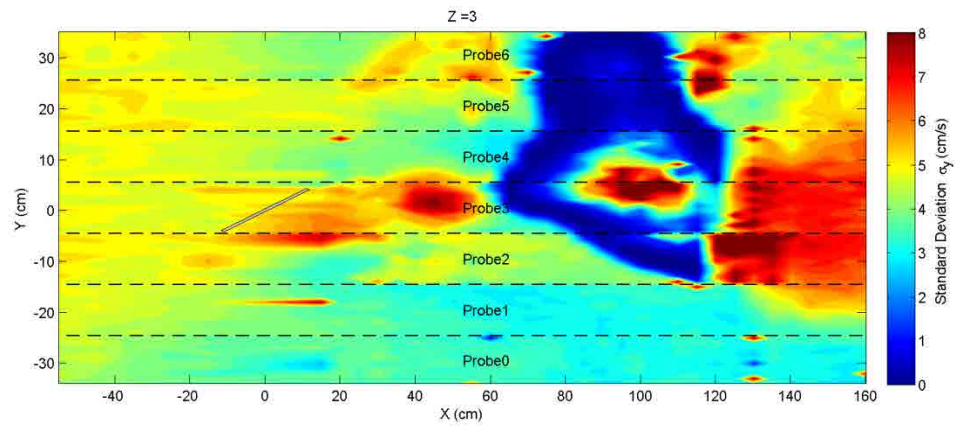
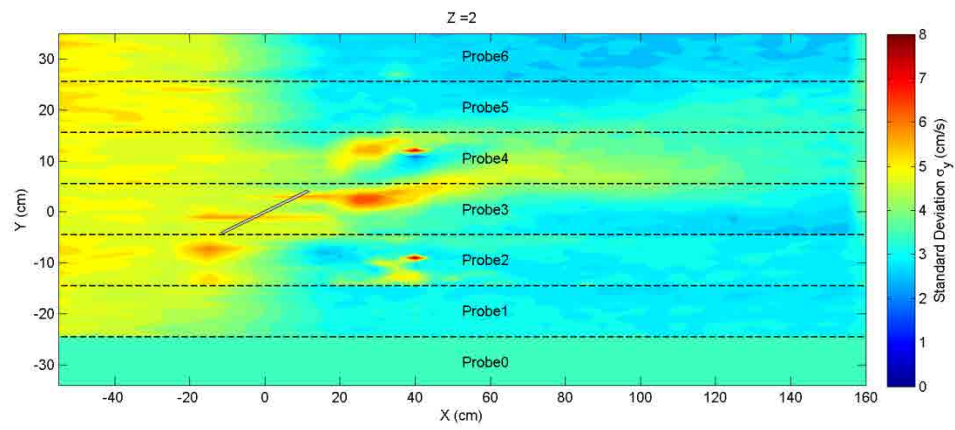
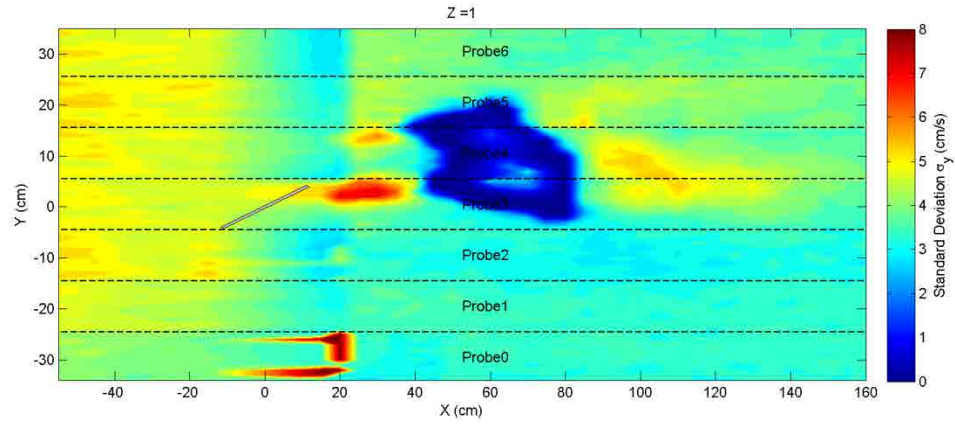


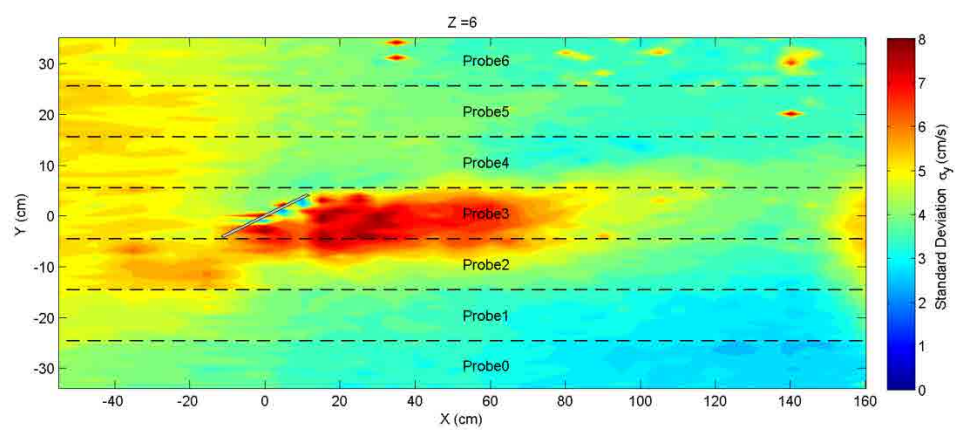
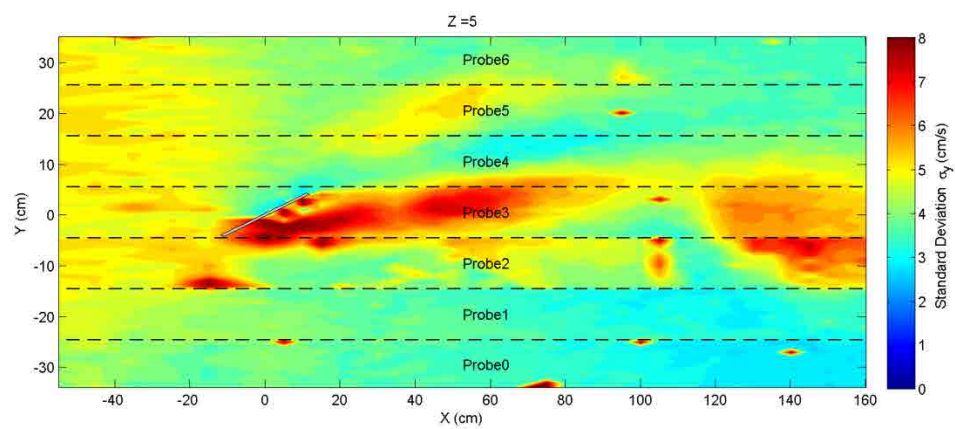
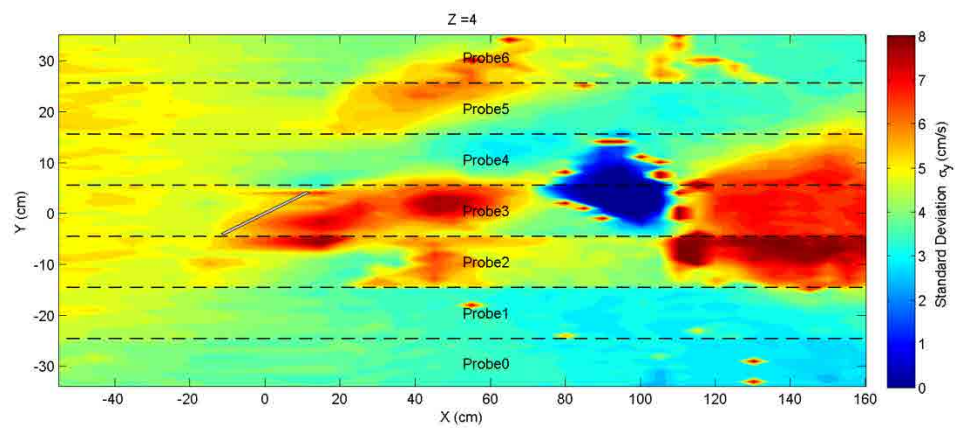




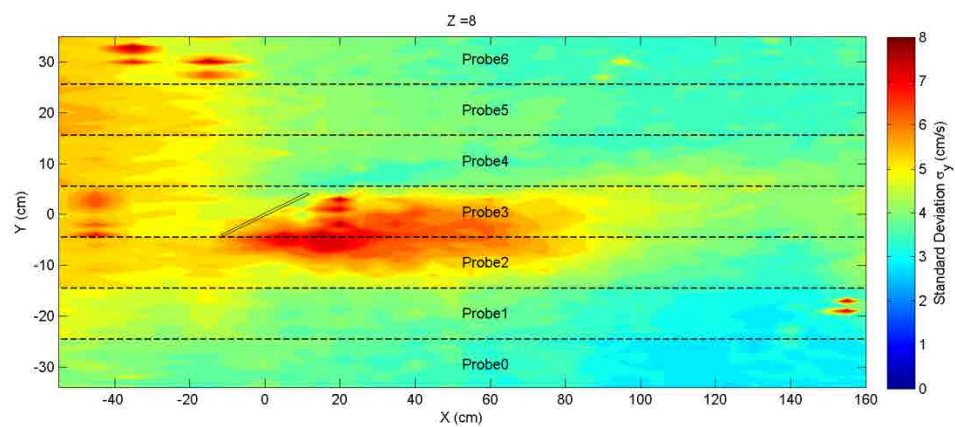
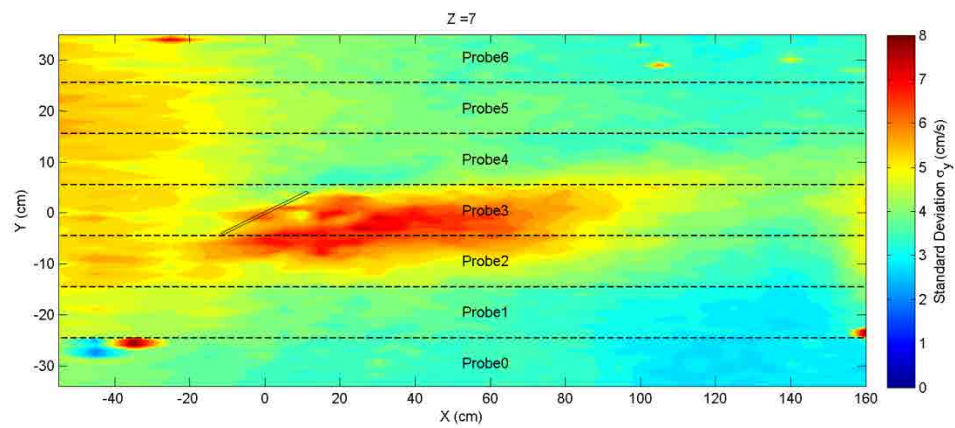


## Standard Deviation $\sigma_y$ in x and y-Directions

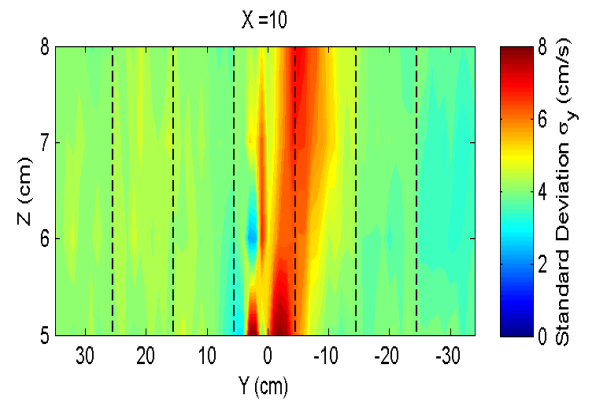
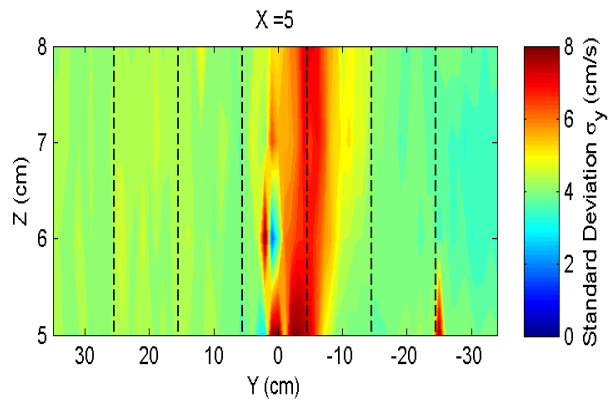
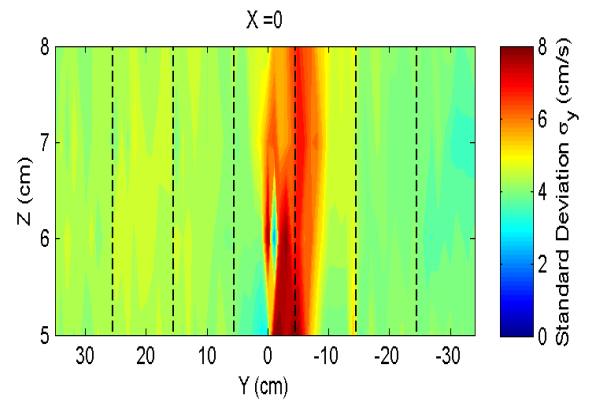
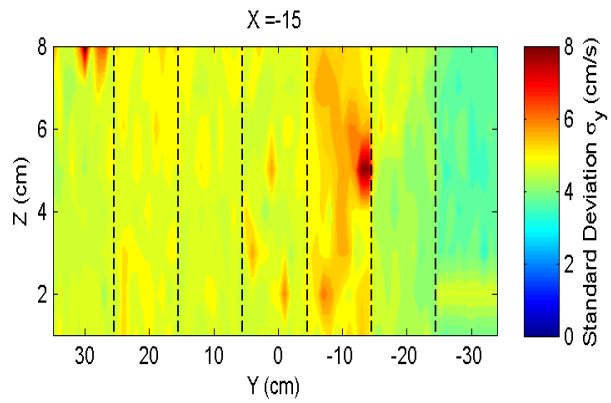
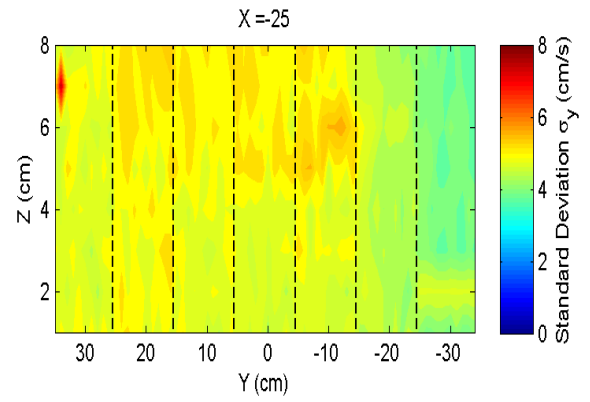
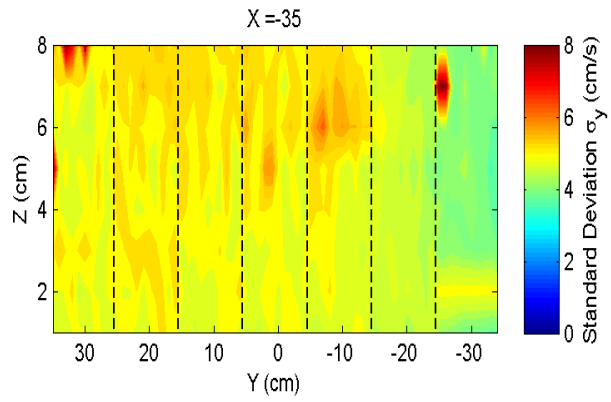
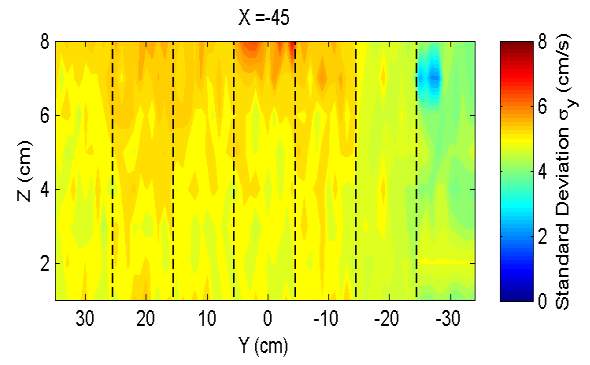
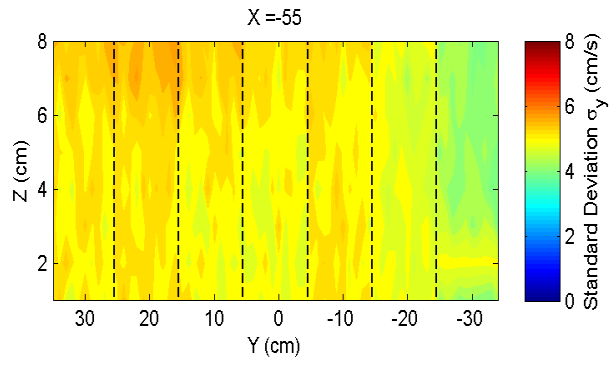




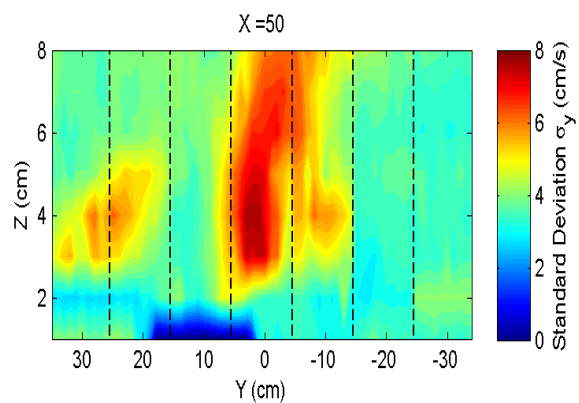
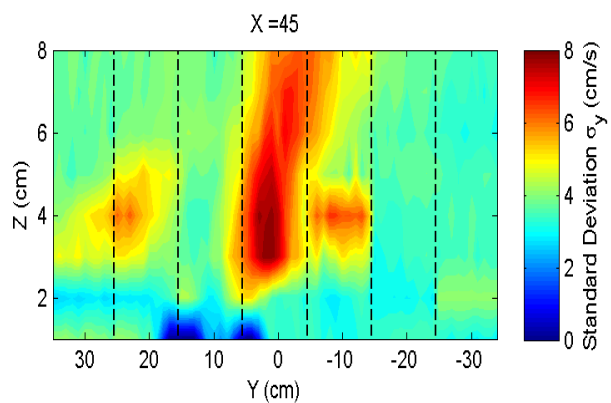
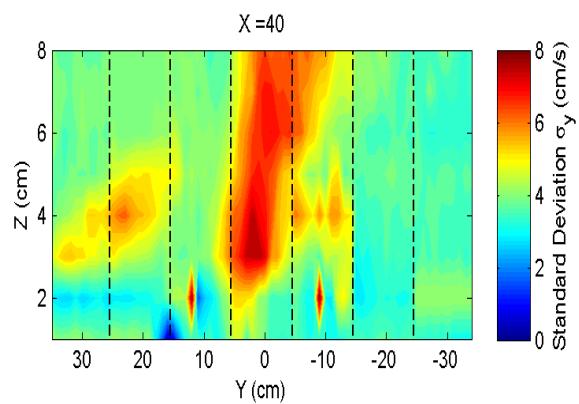
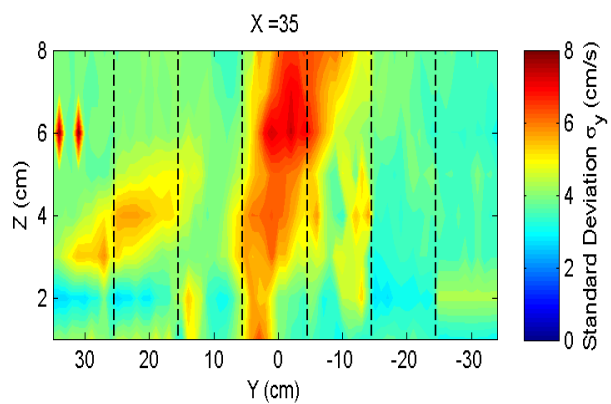
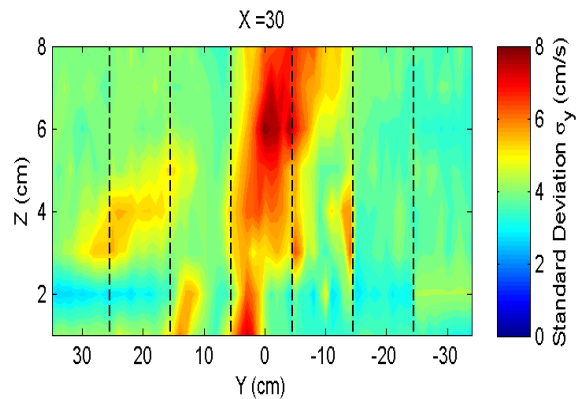
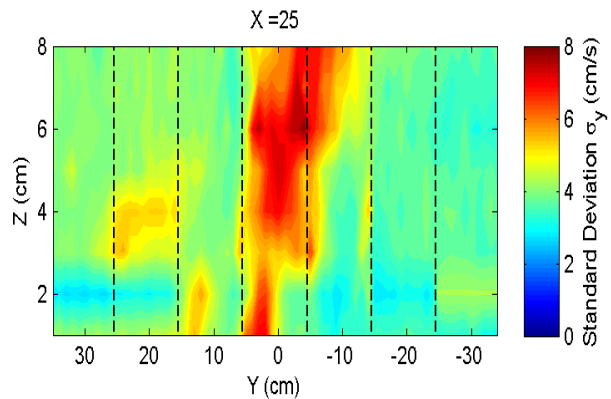
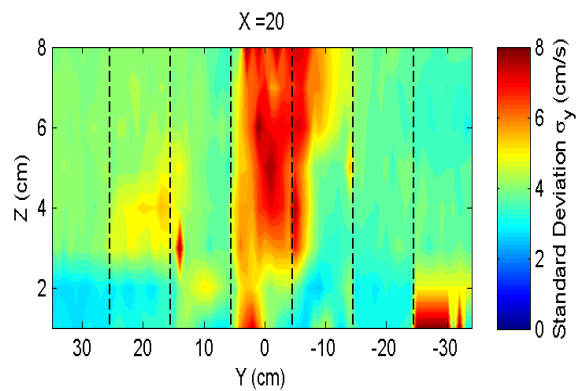
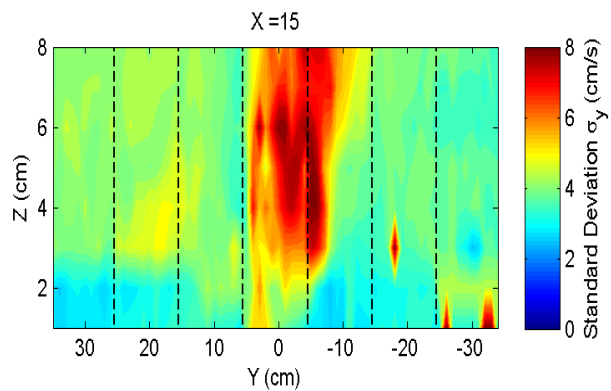


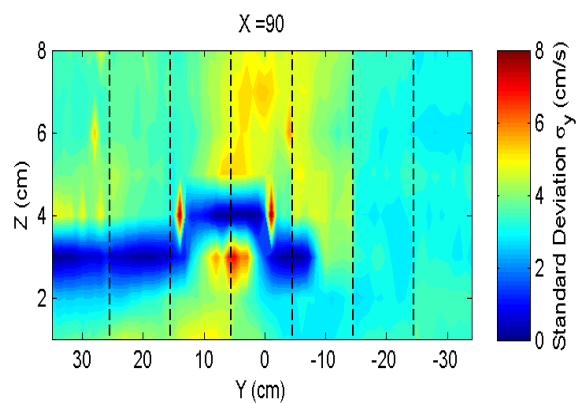
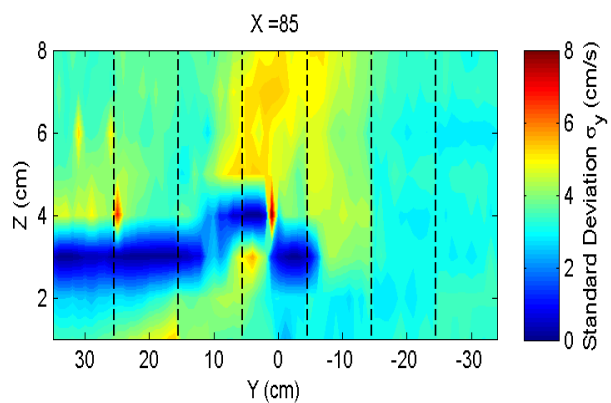
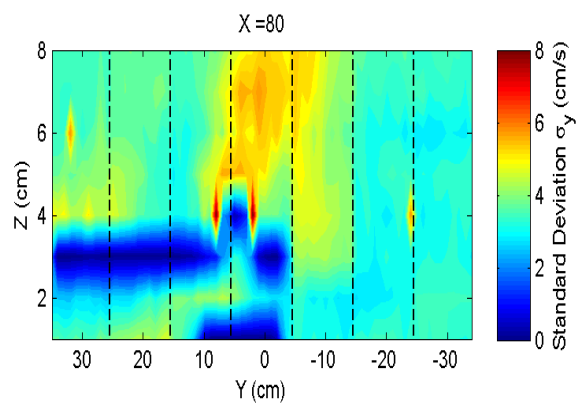
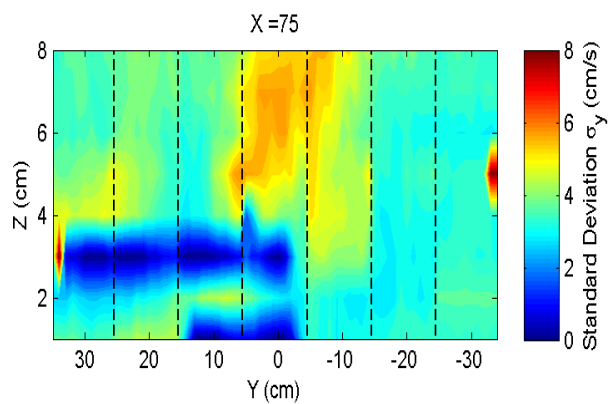
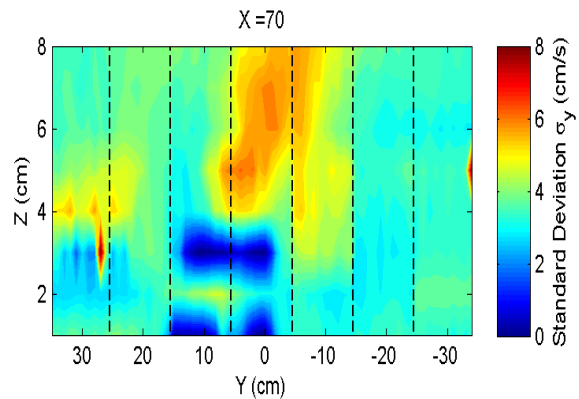
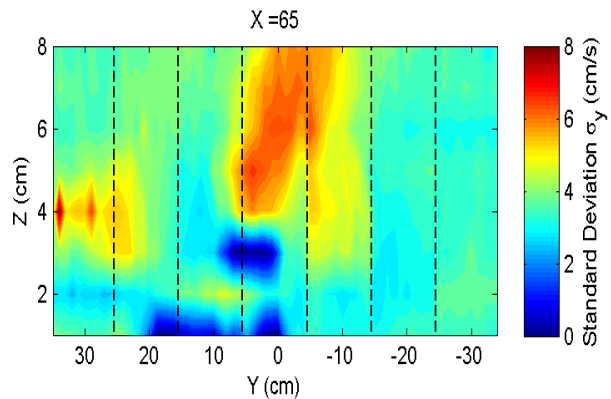
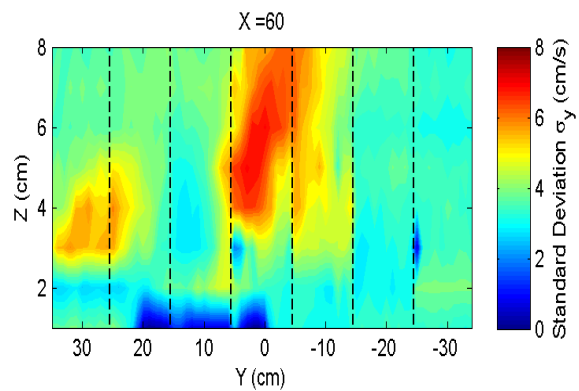
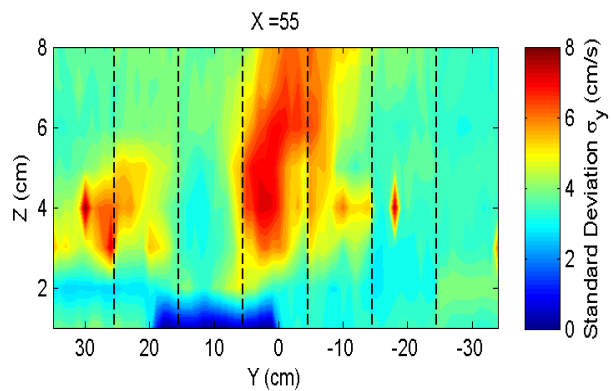


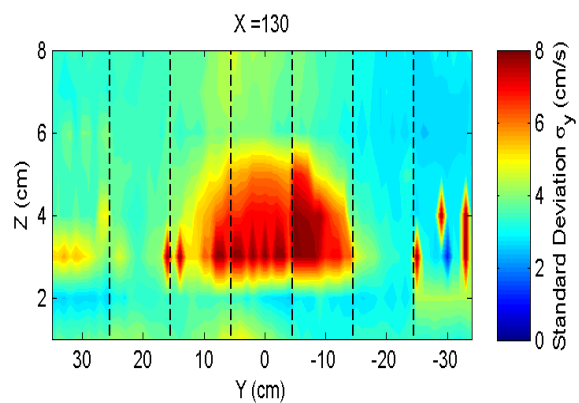
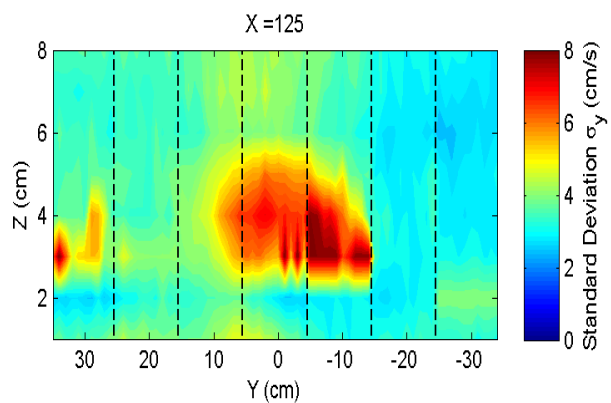
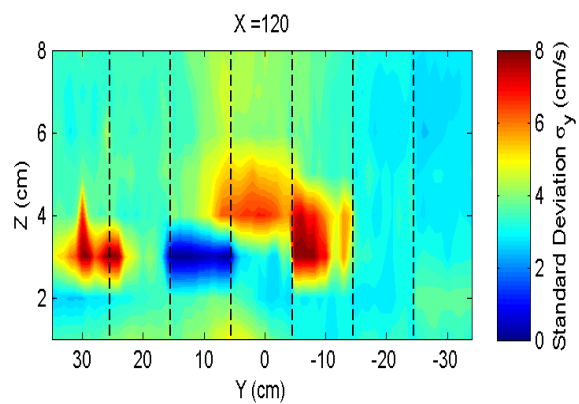
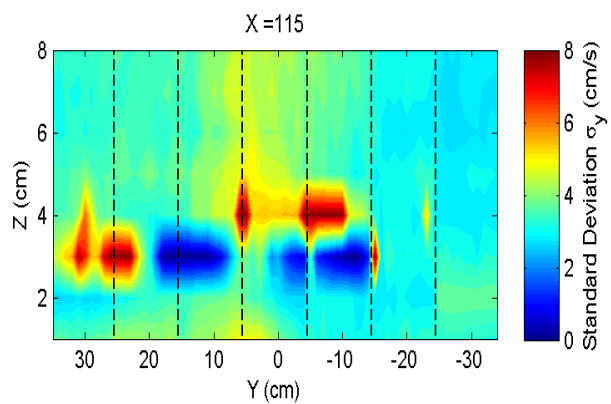
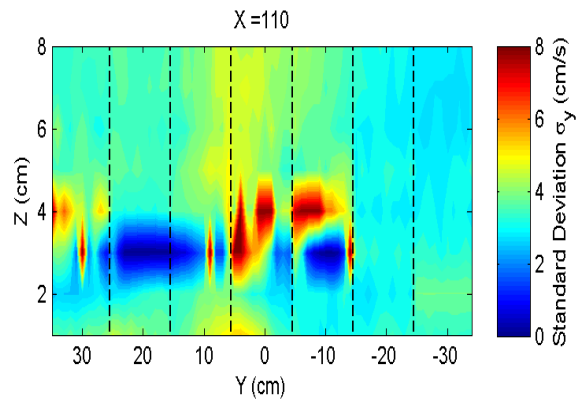
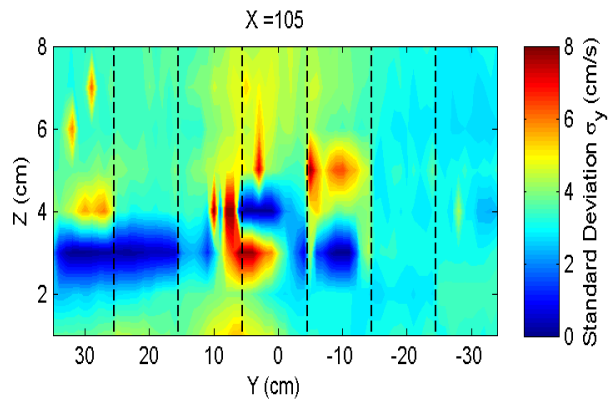
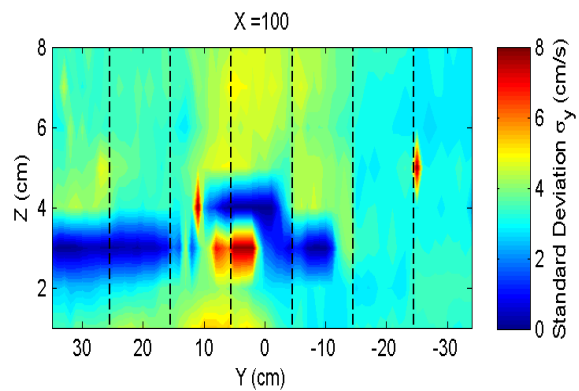
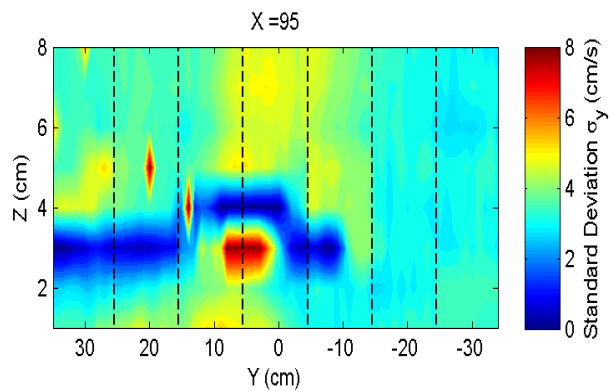
## Standard Deviation $\sigma_y$ in y and z-Directions

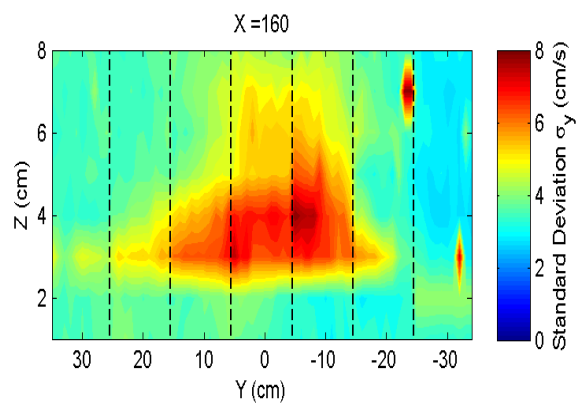
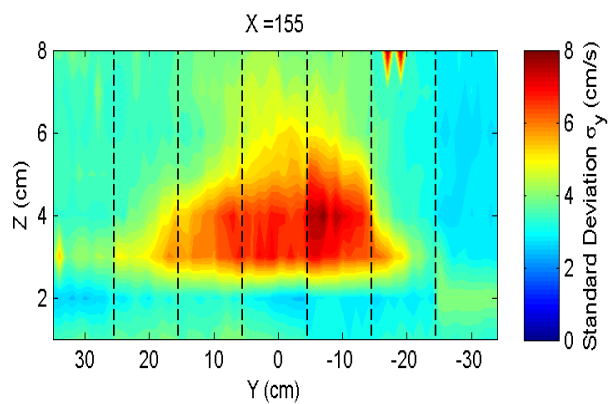
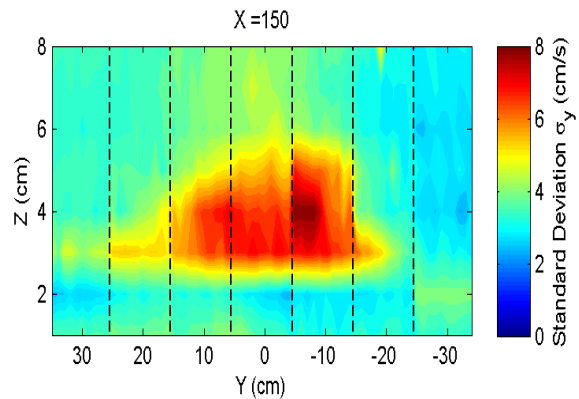
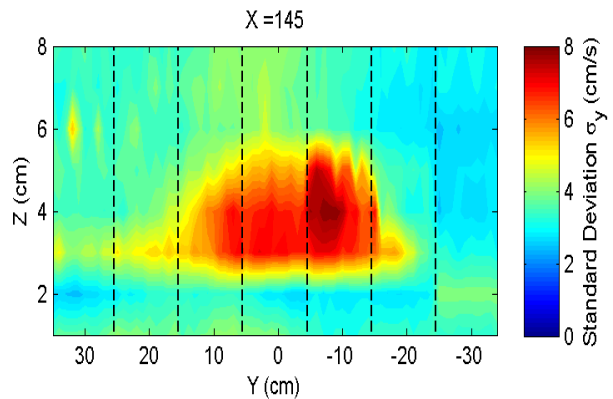
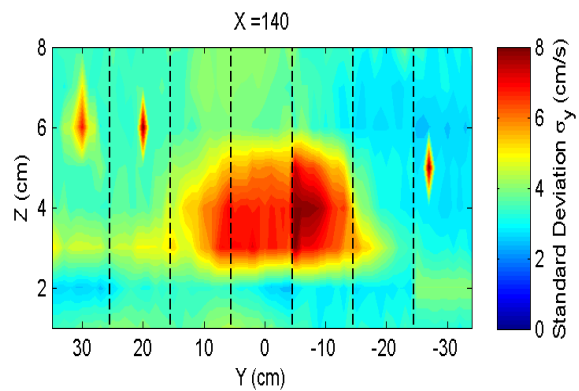
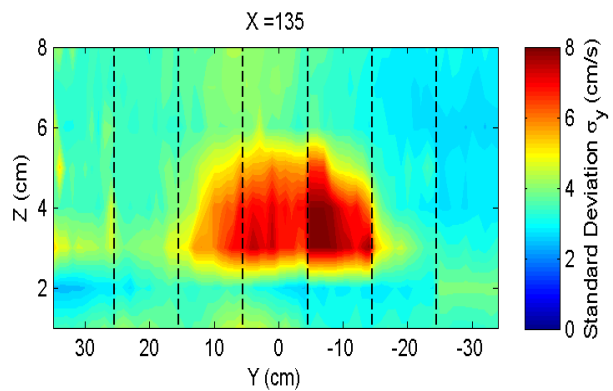




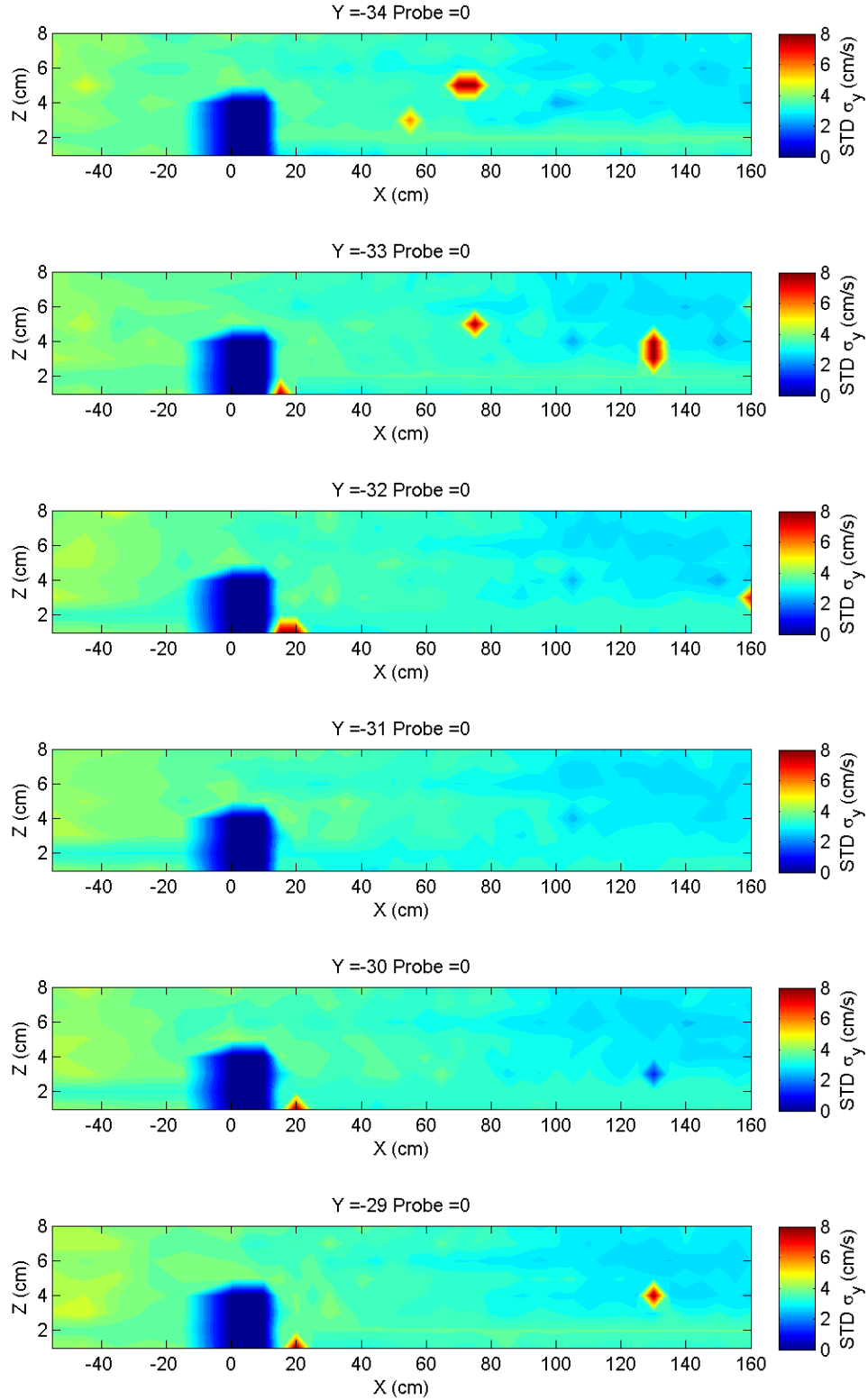


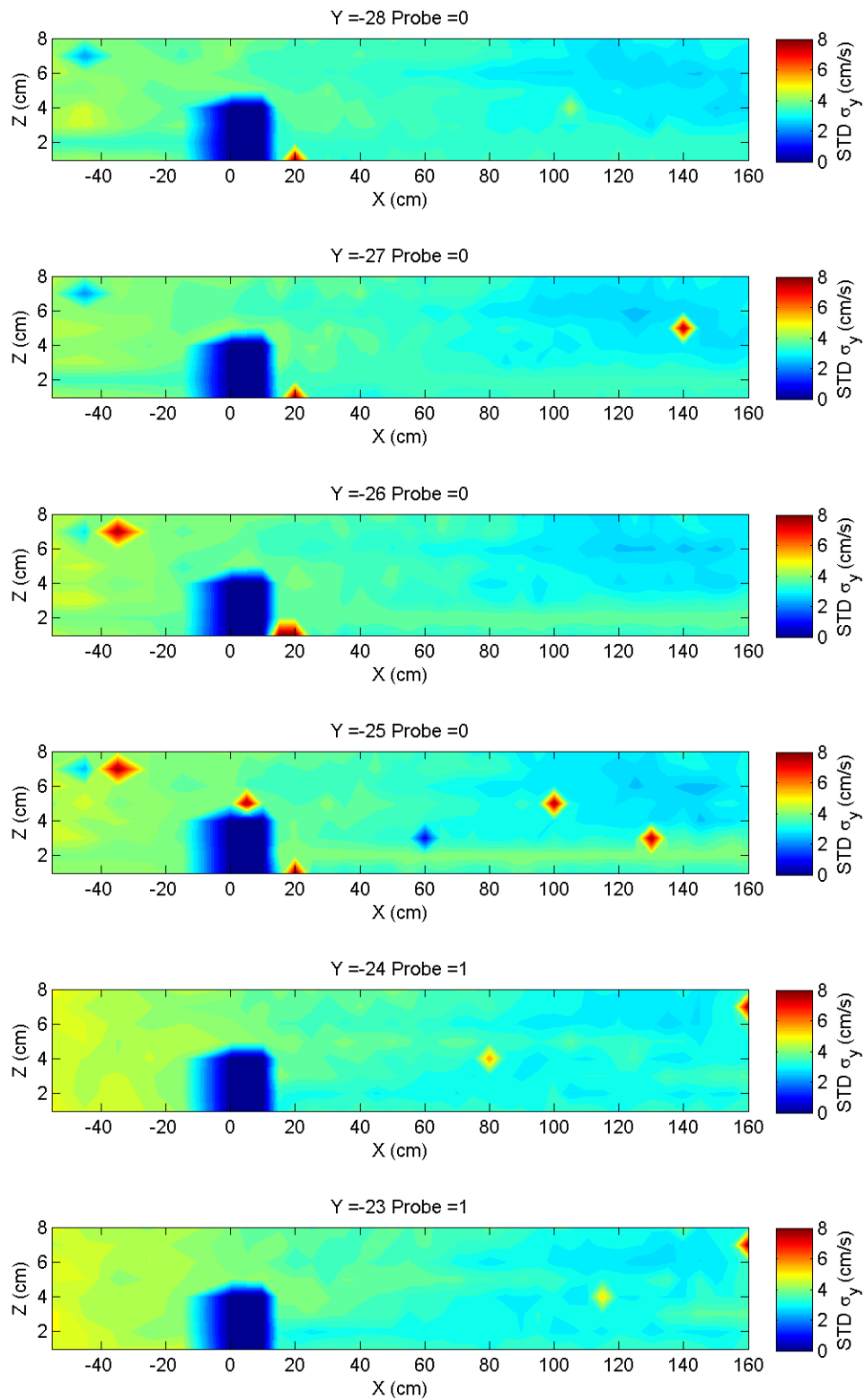


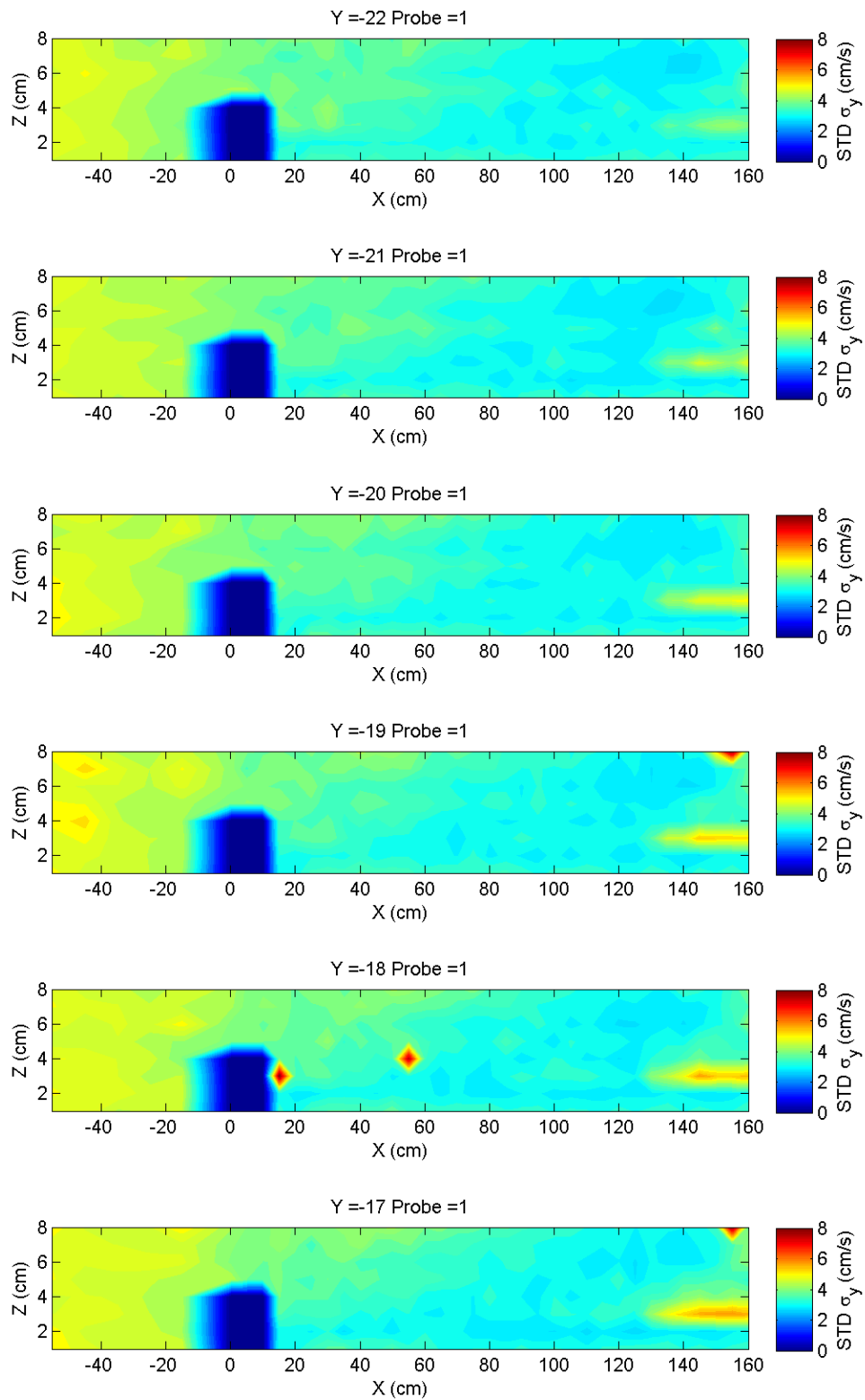


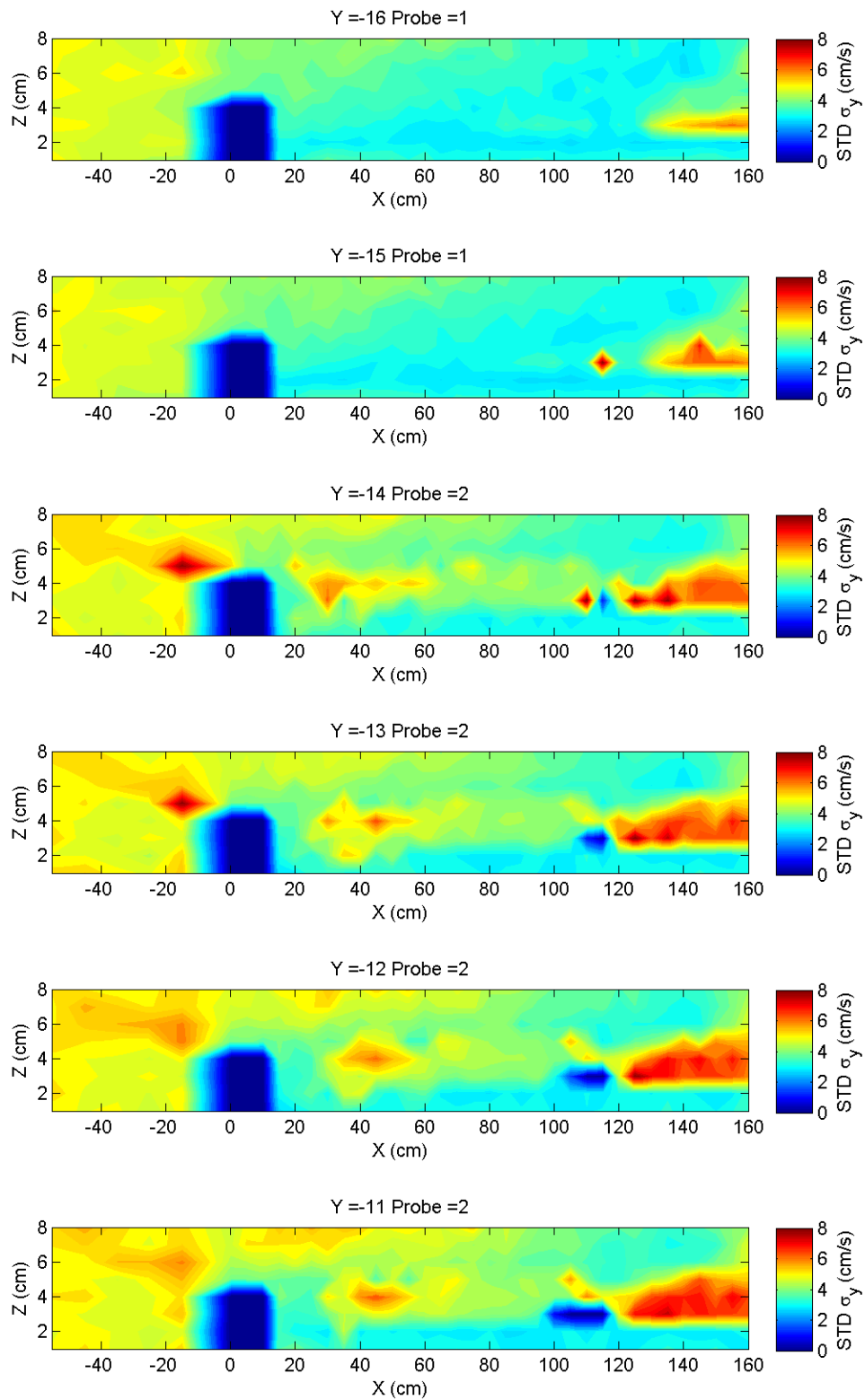


## Standard Deviation $\sigma_y$ in x and z-Directions

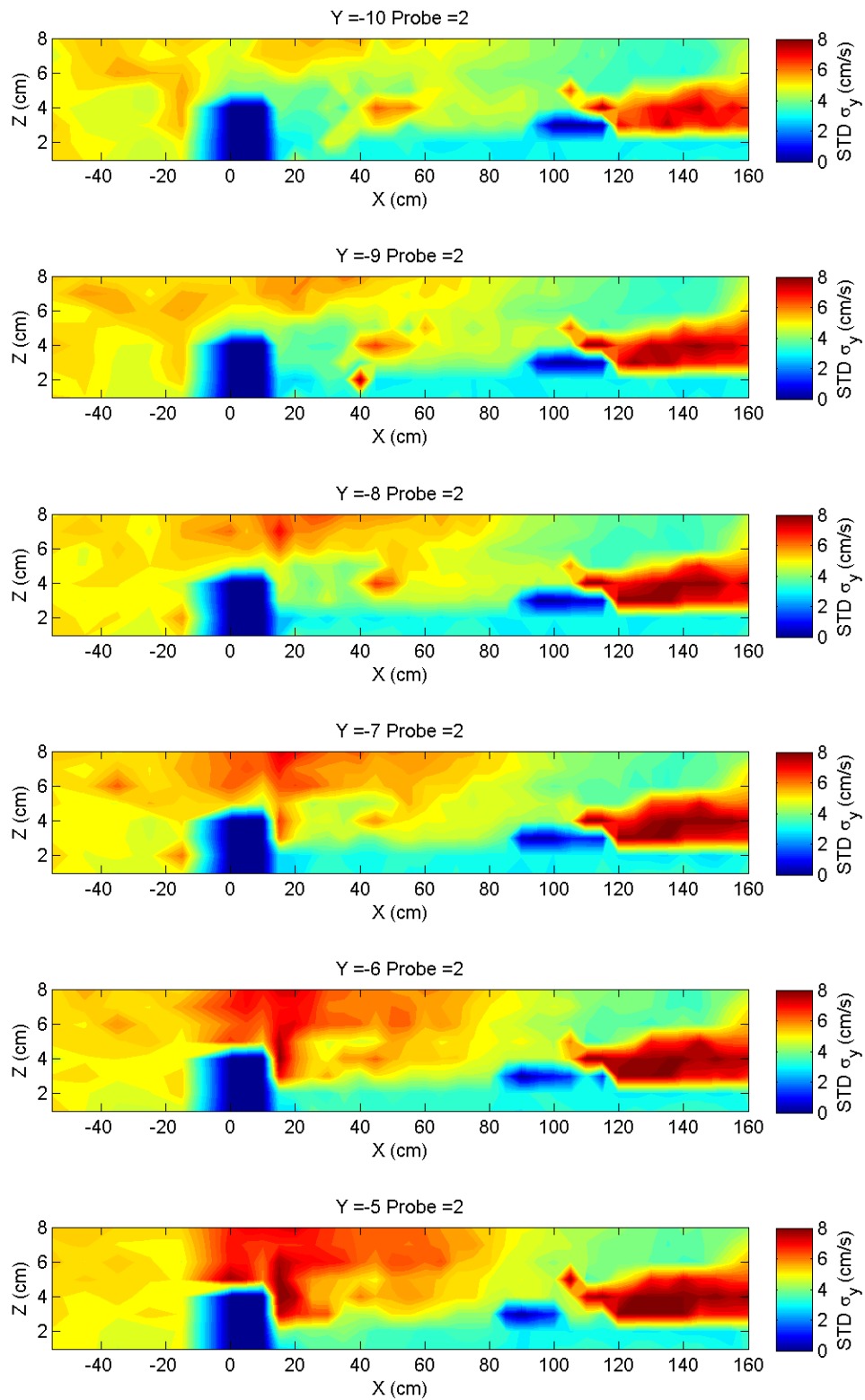


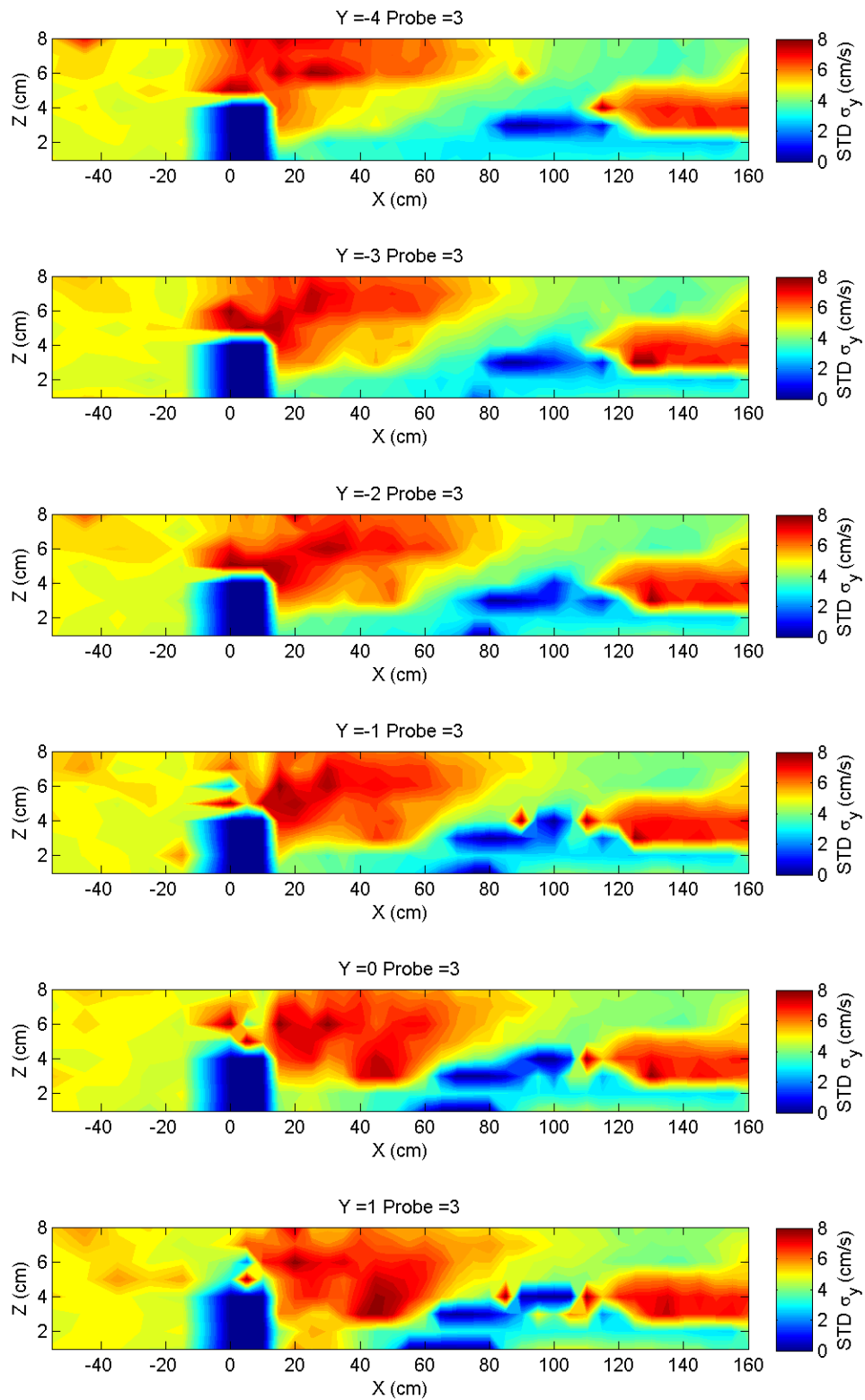


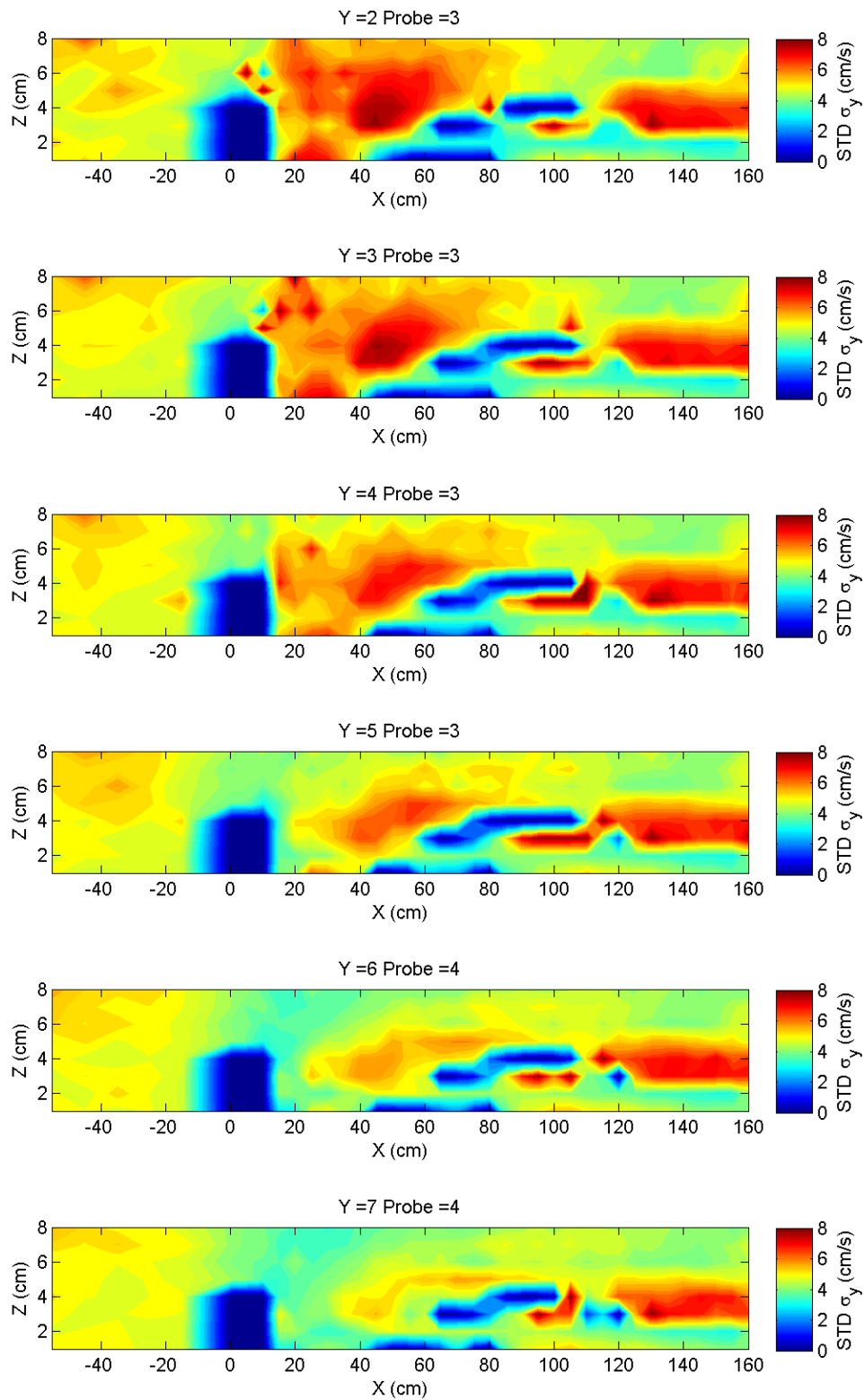


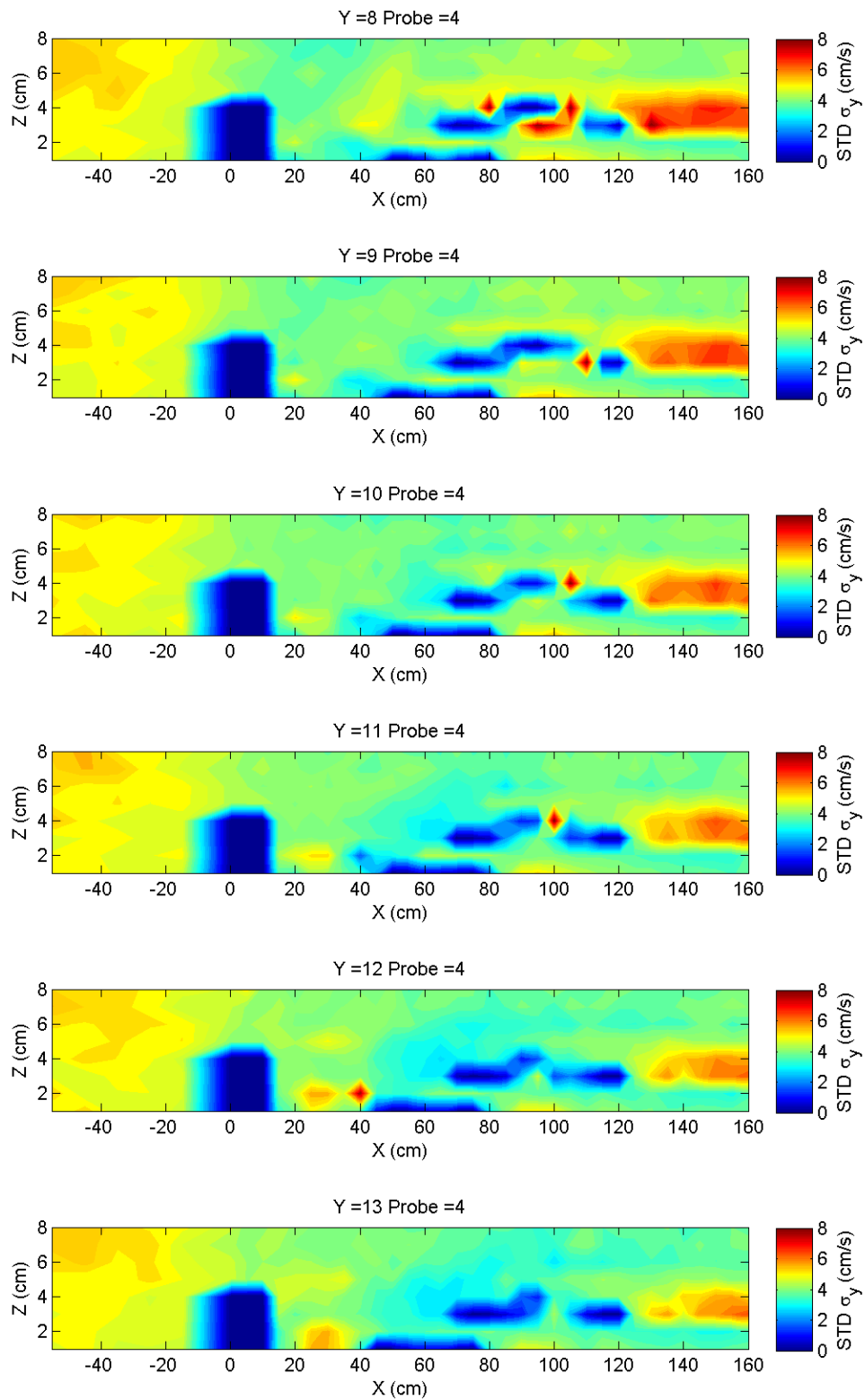


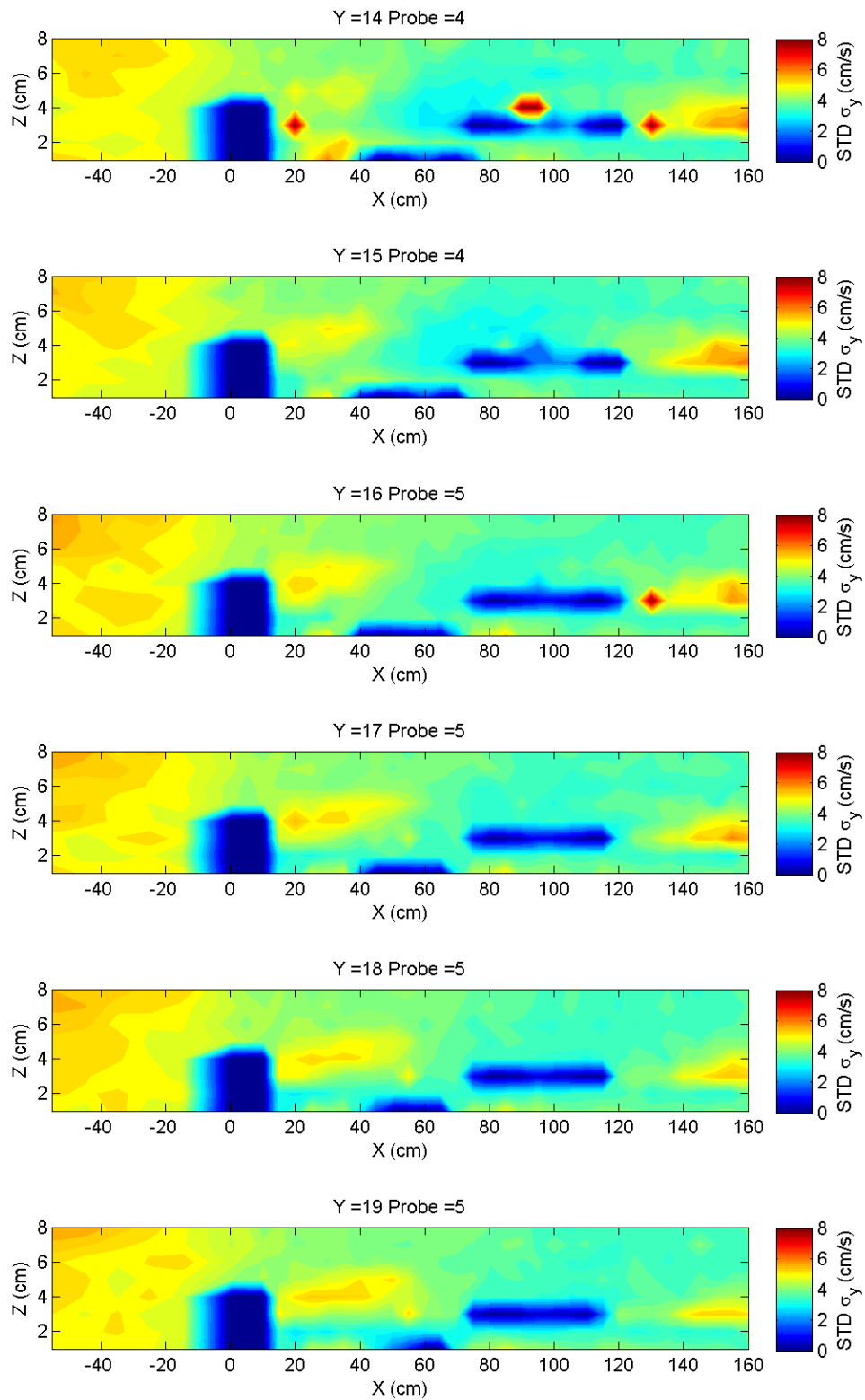






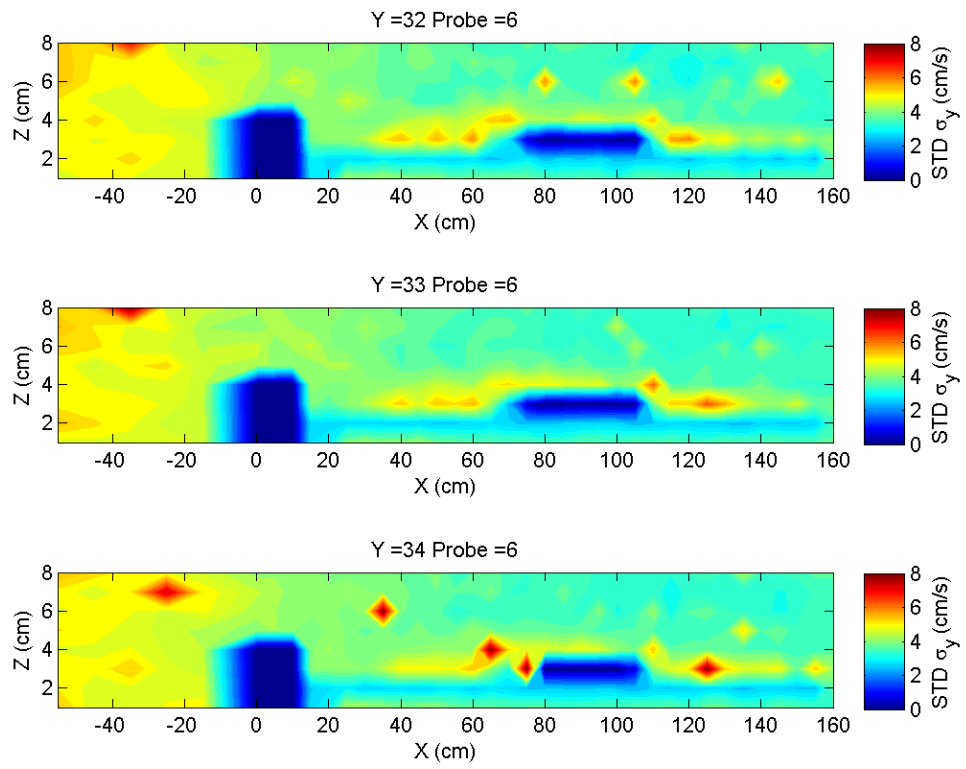






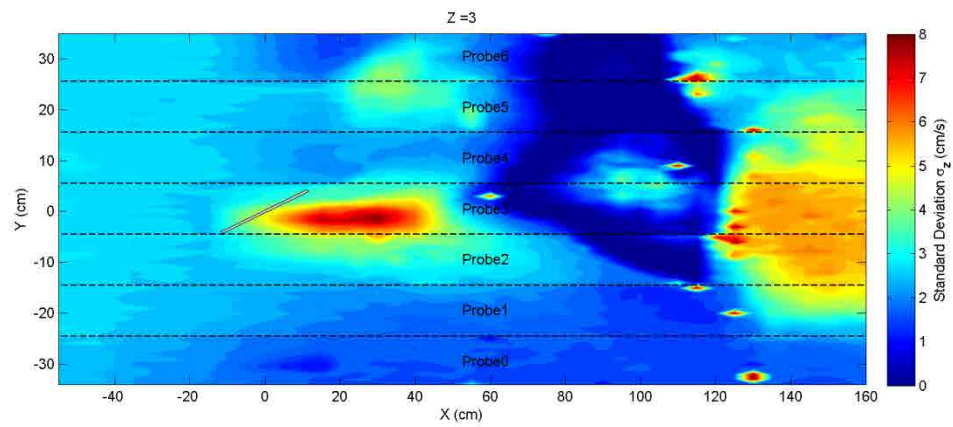
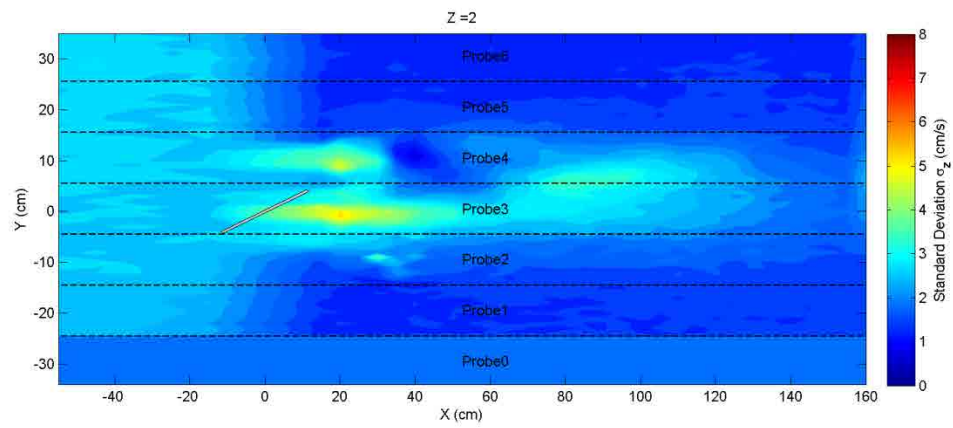
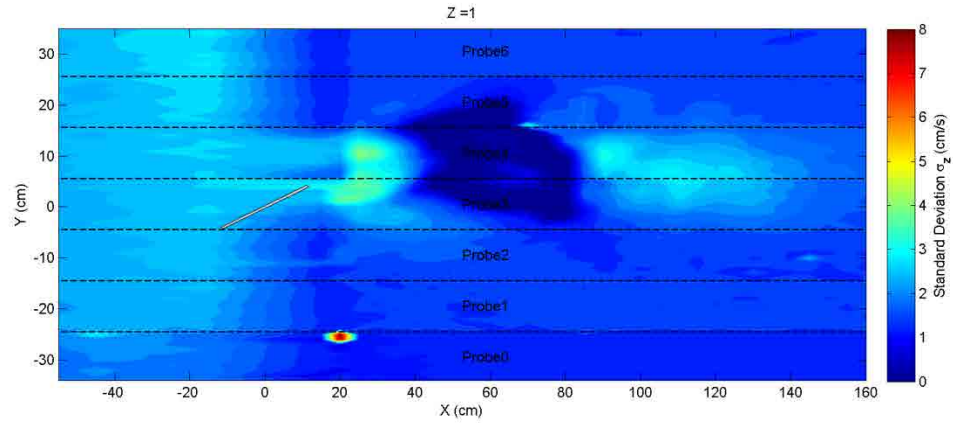


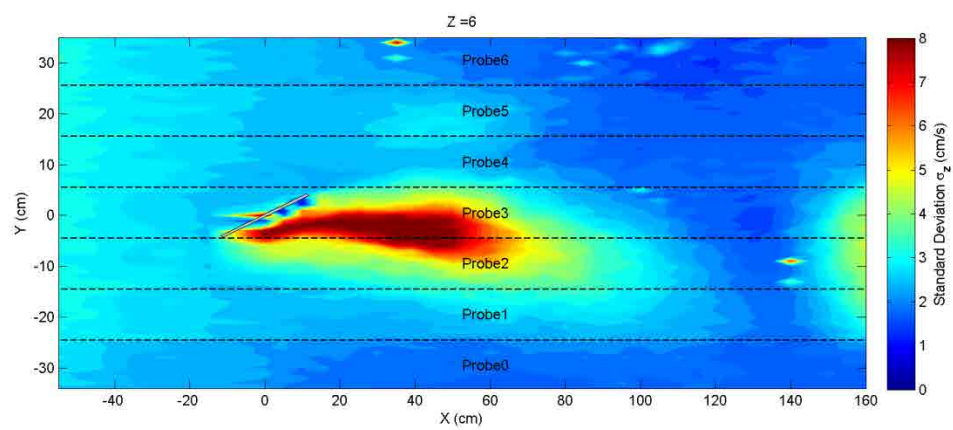
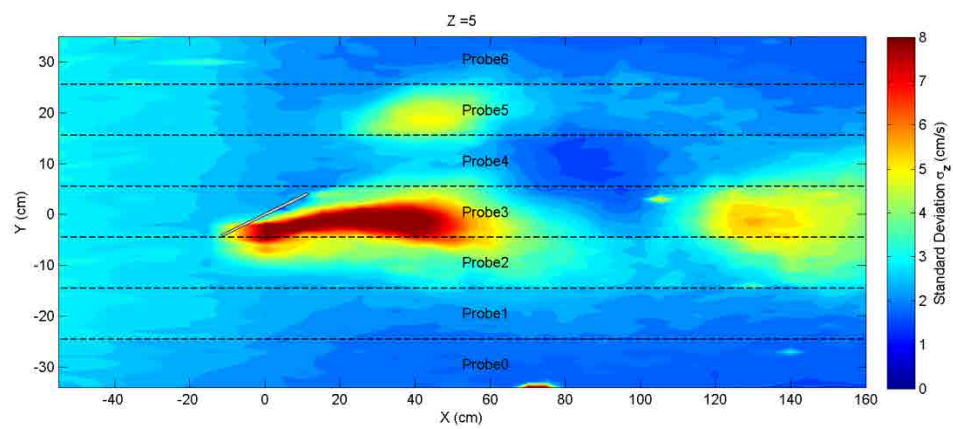
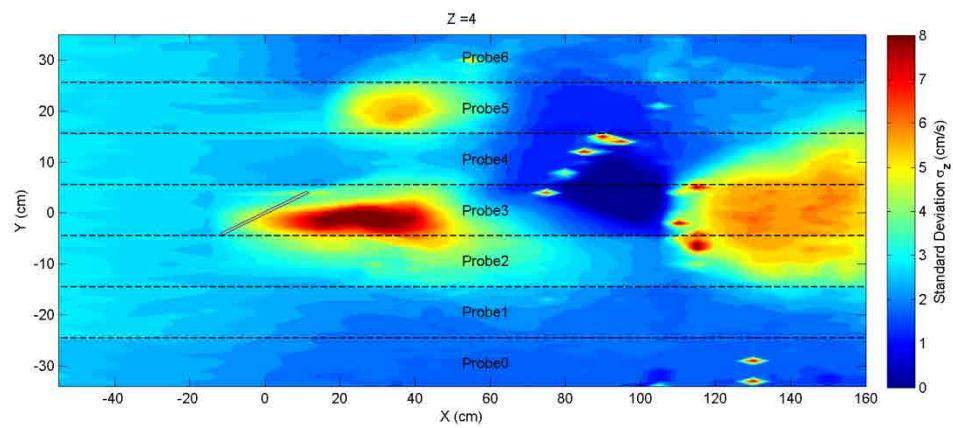


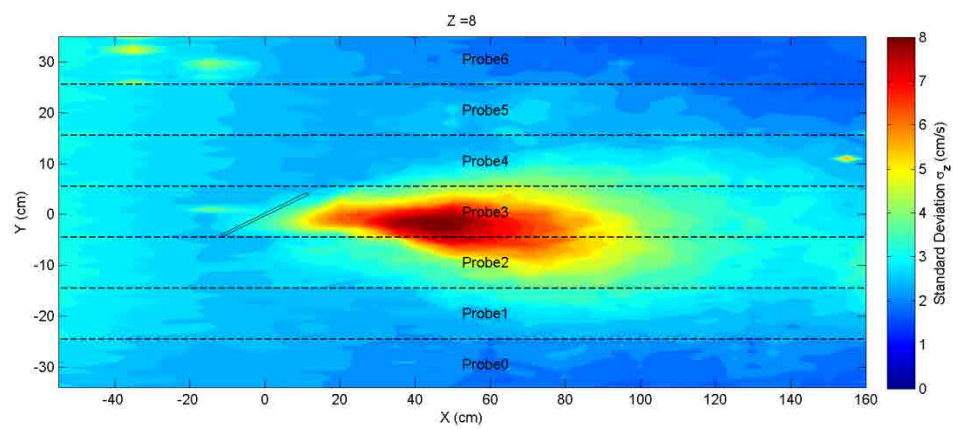
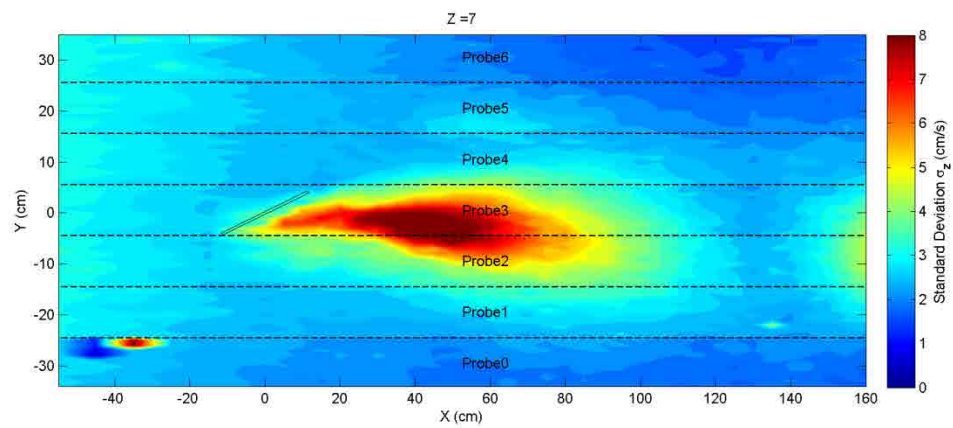




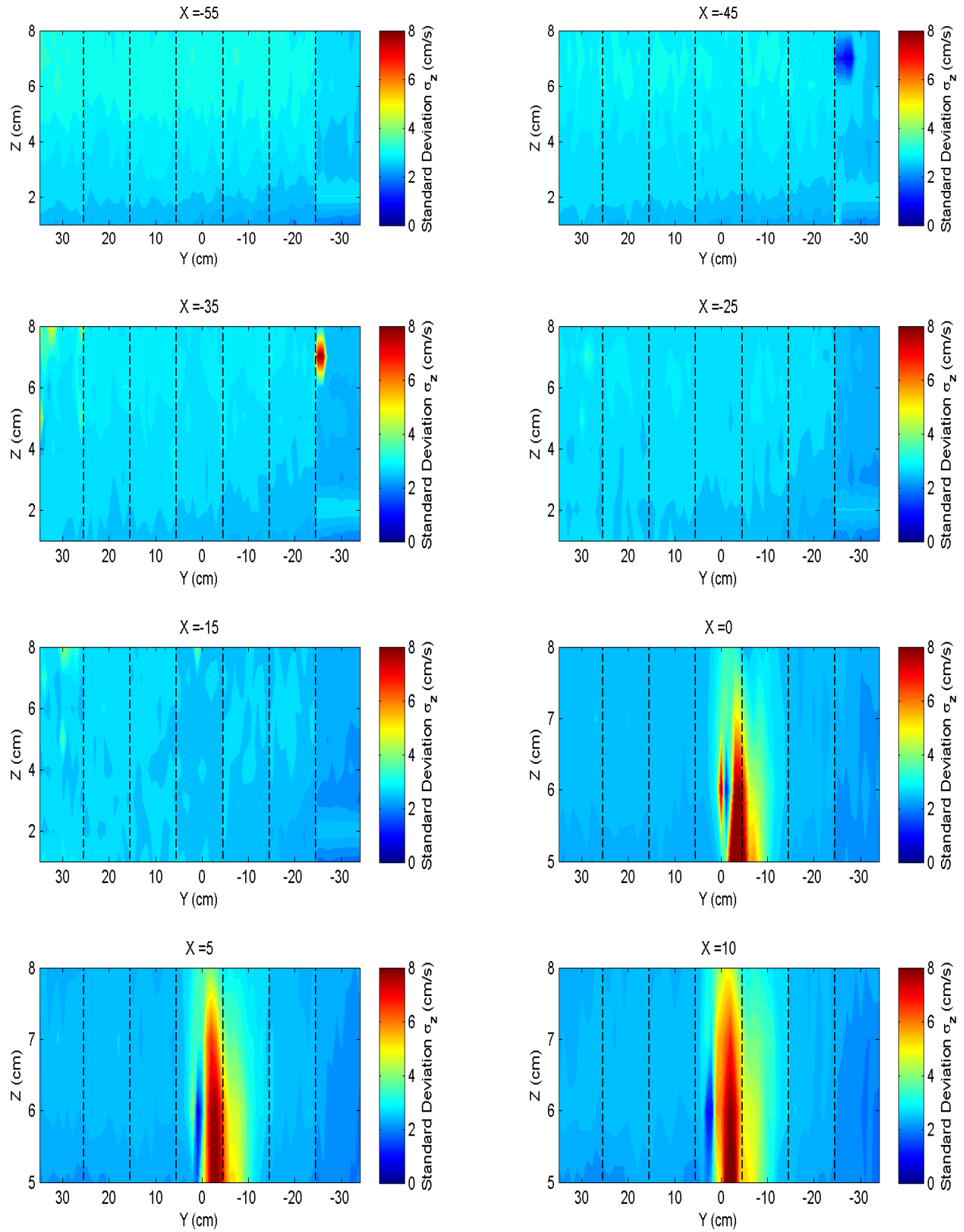
## Standard Deviation $\sigma_z$ in x and y-Directions

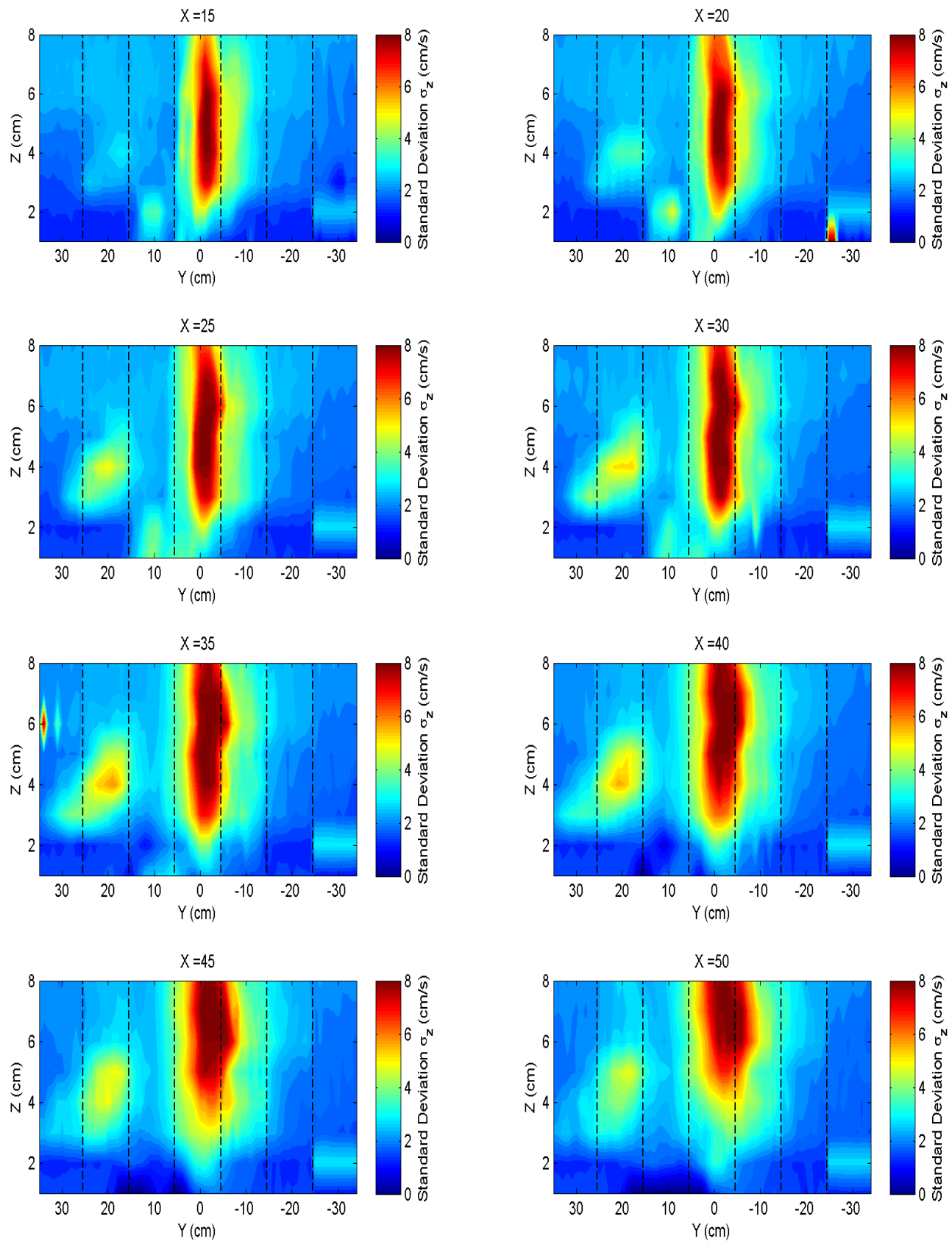


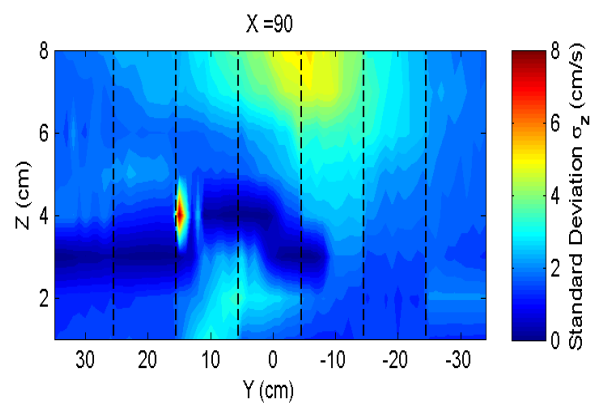
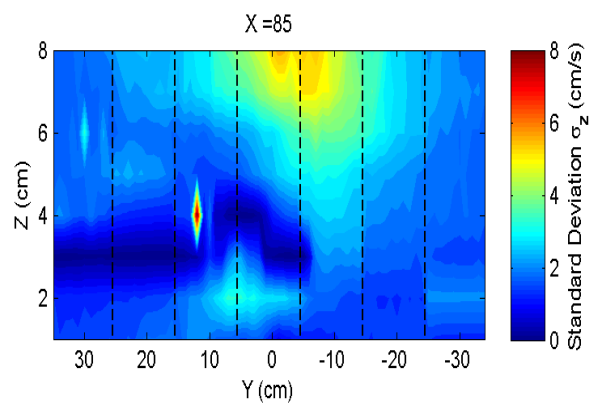
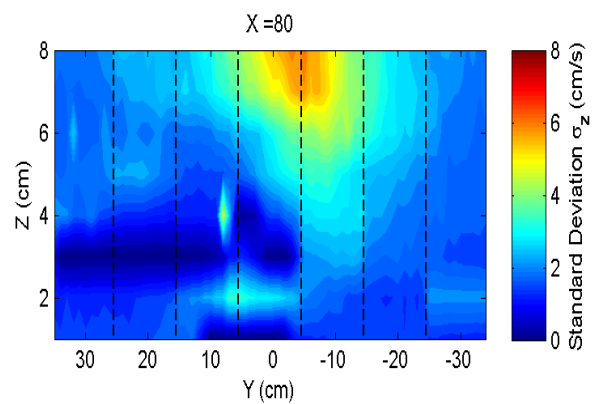
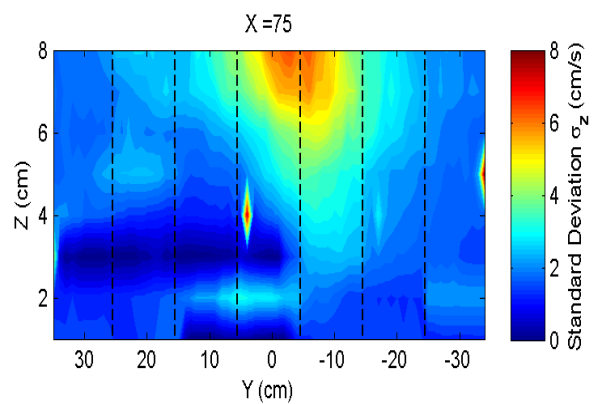
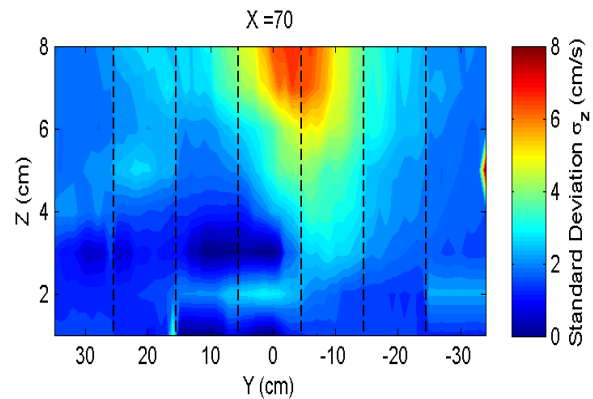
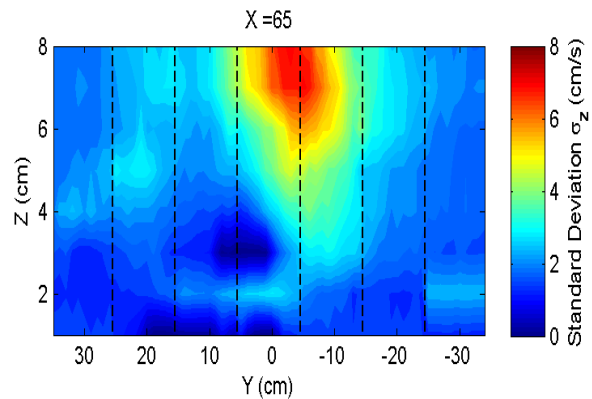
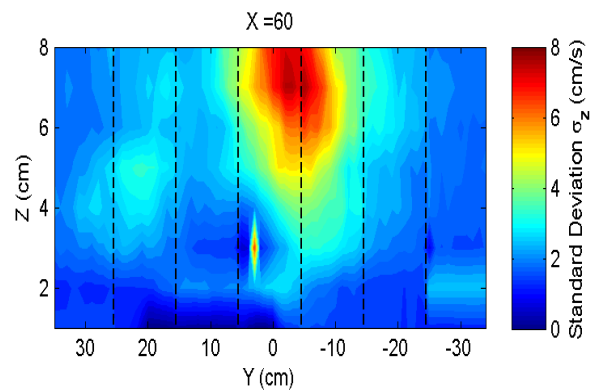
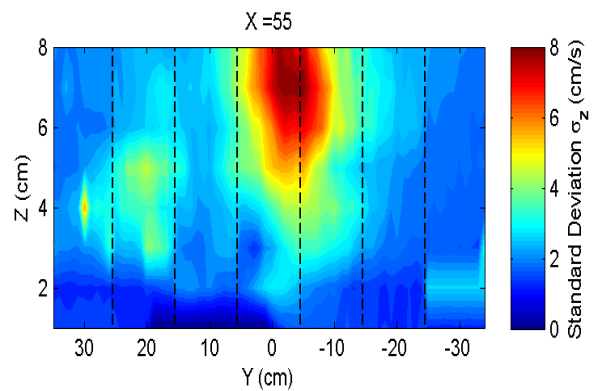




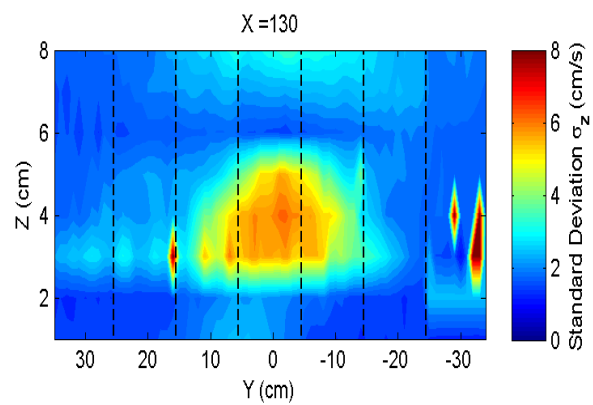
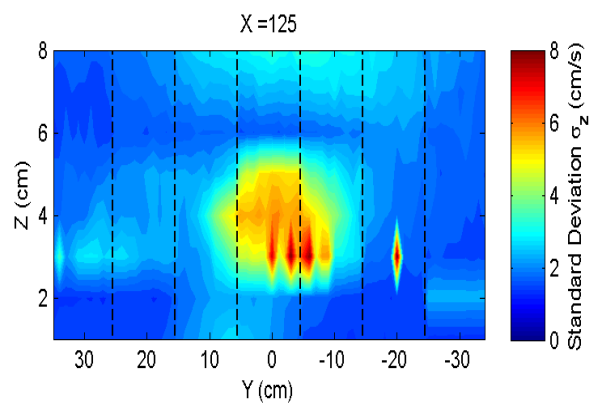
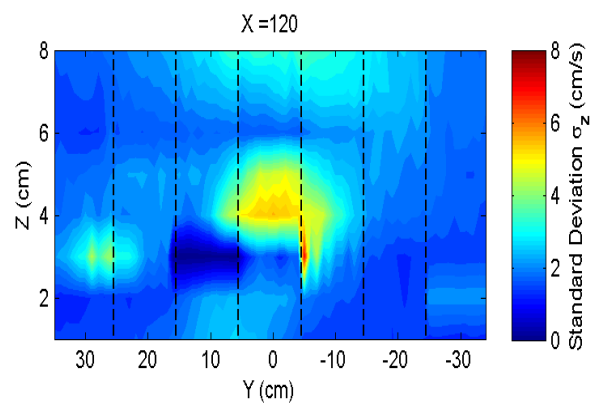
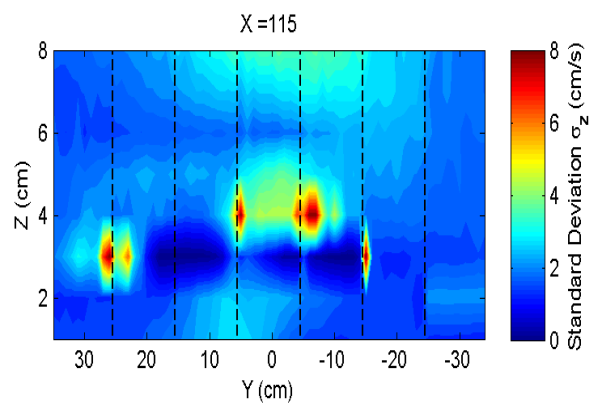
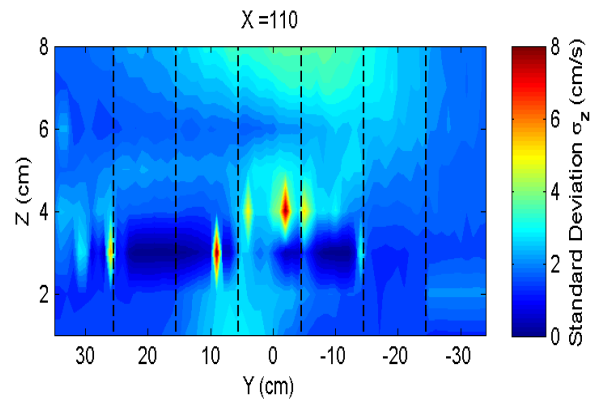
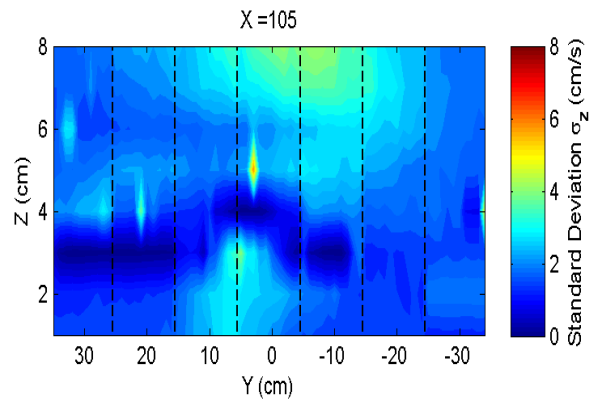
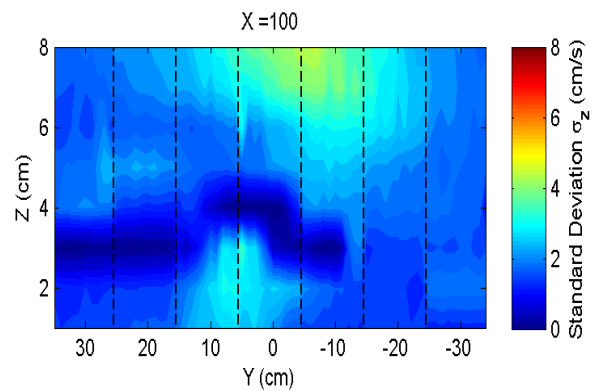
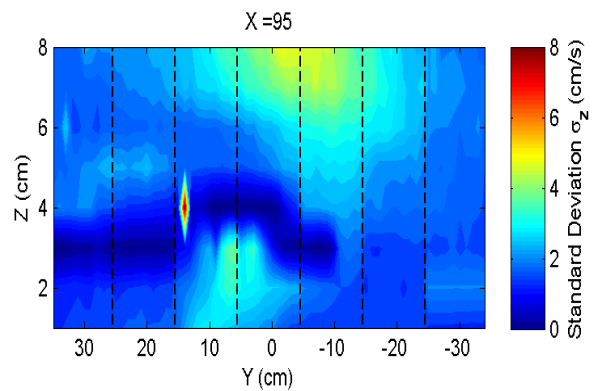
## Standard Deviation $\sigma_z$ in y and z-Directions



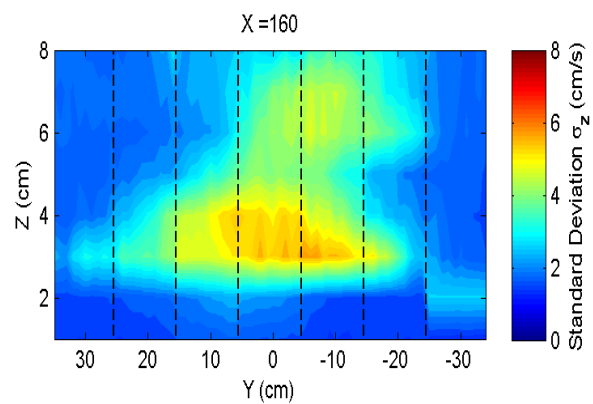
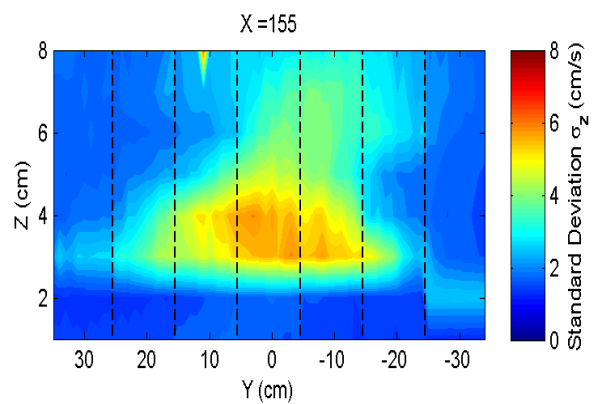
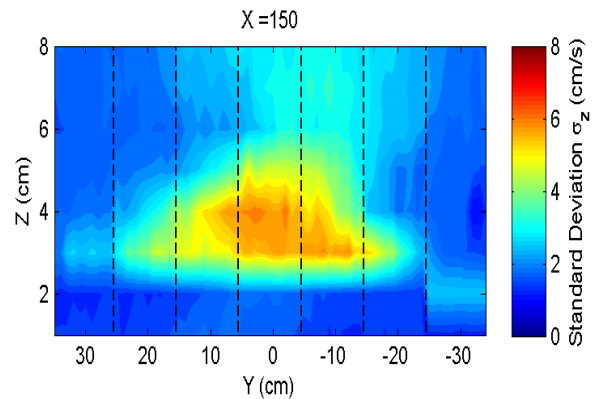
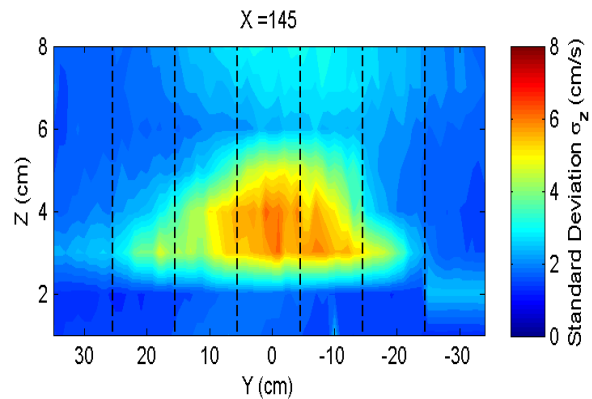
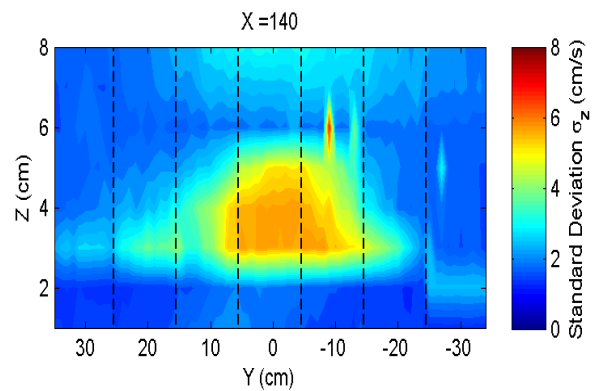
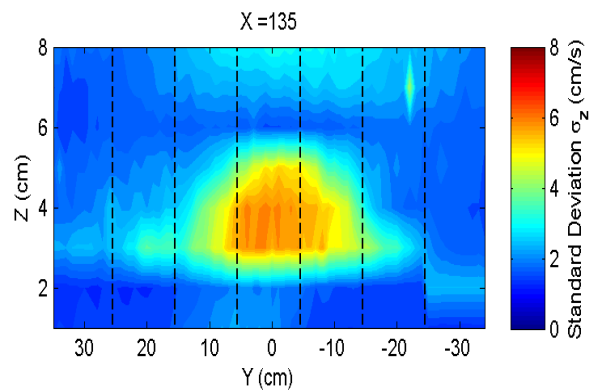




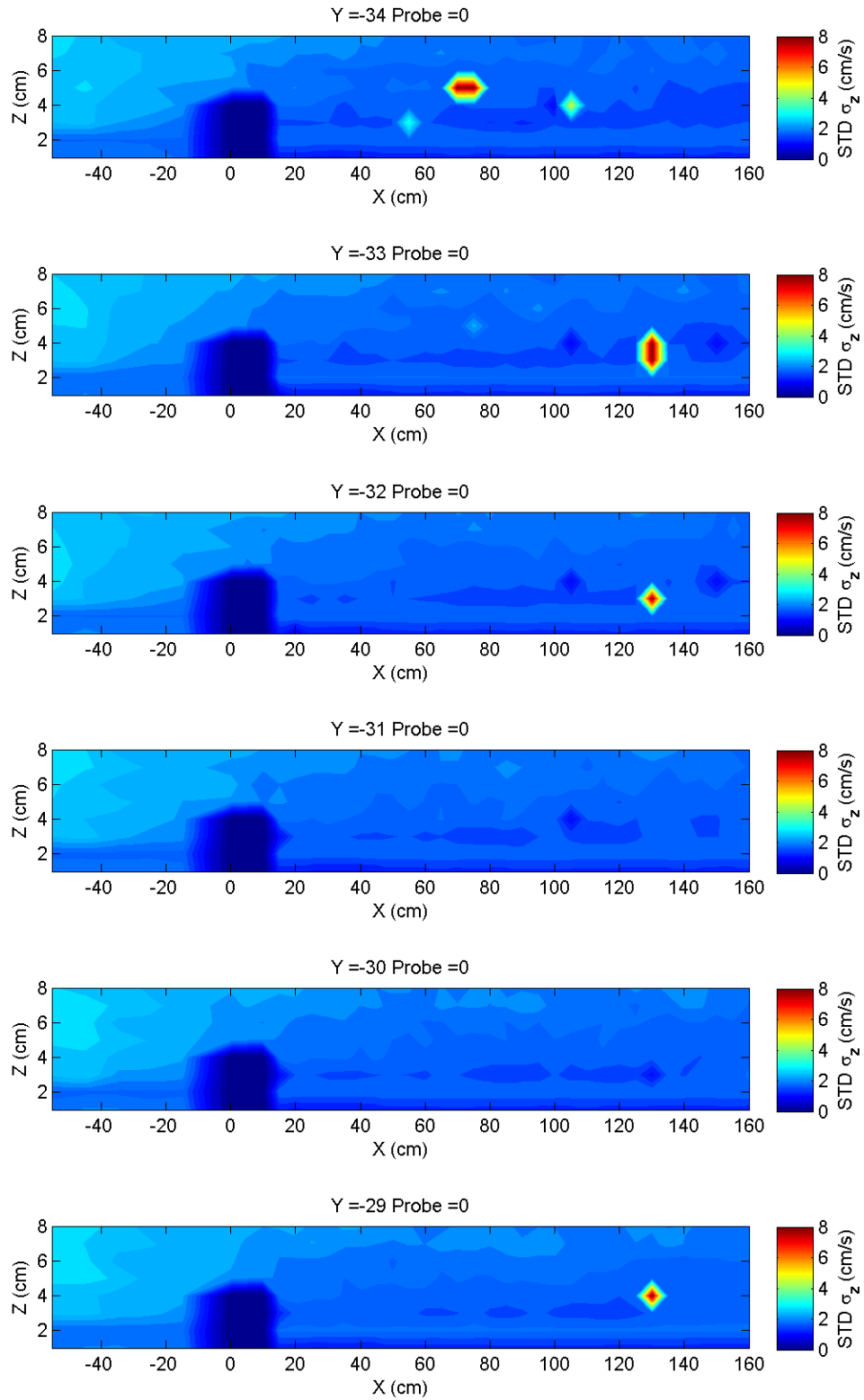


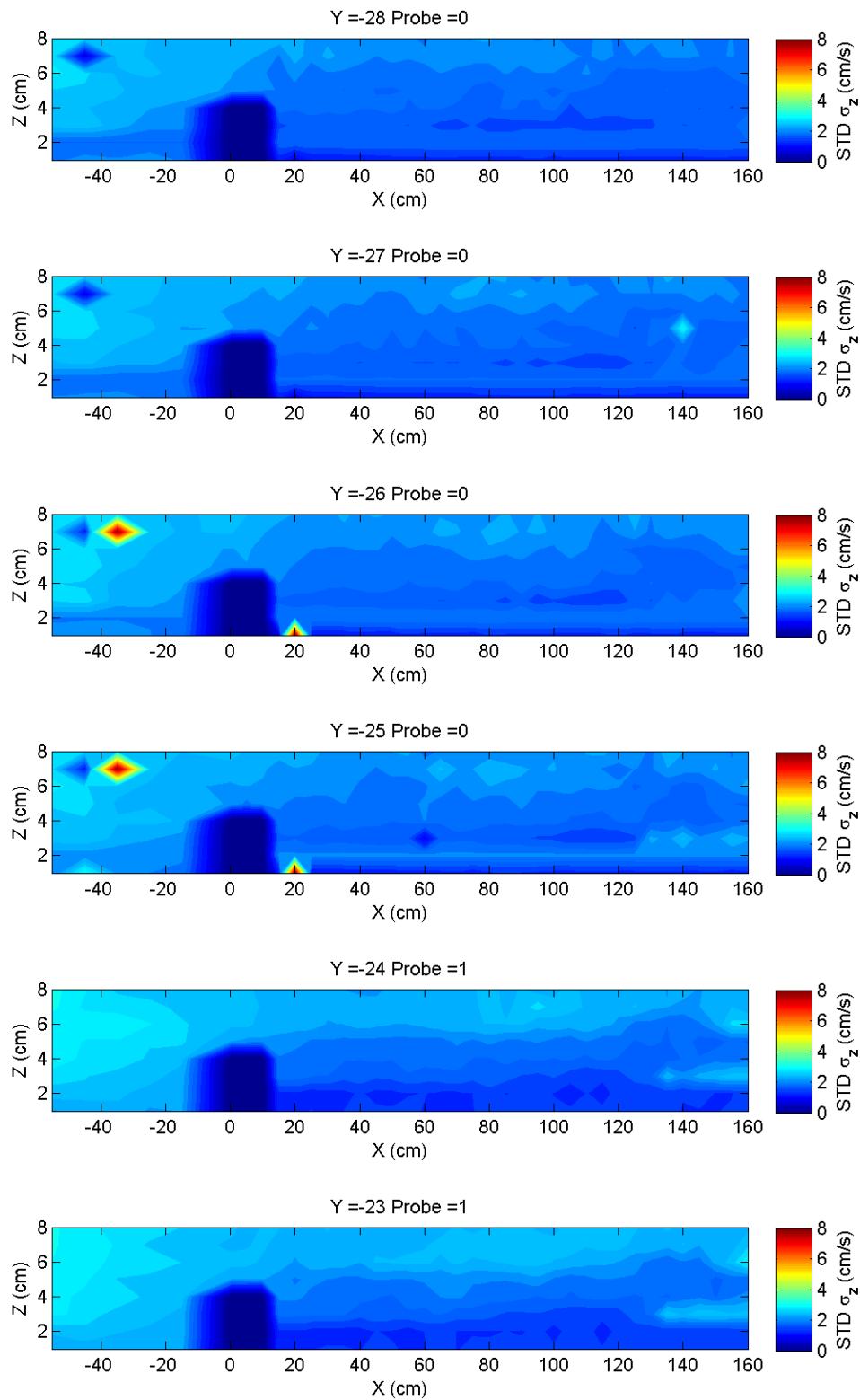


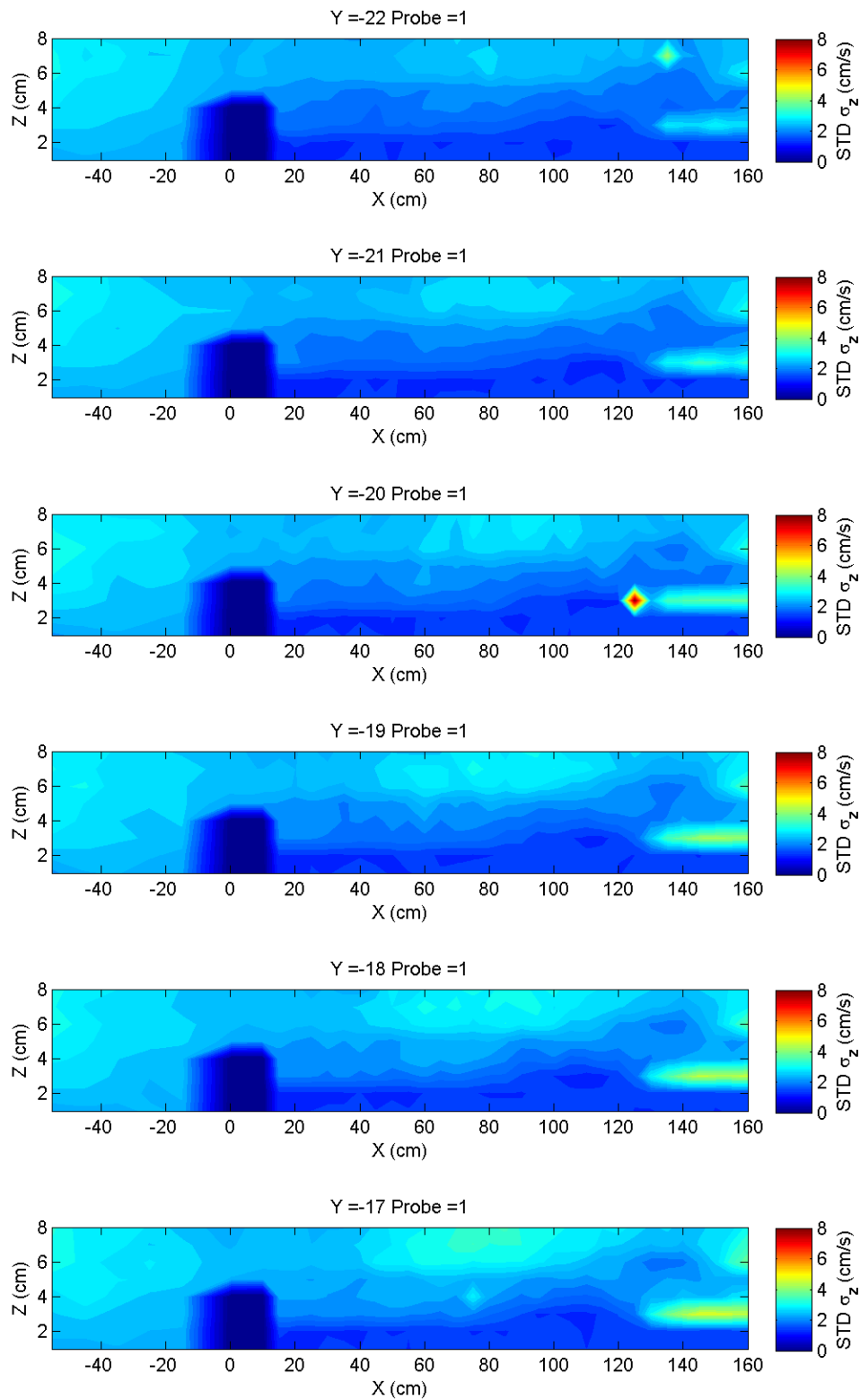


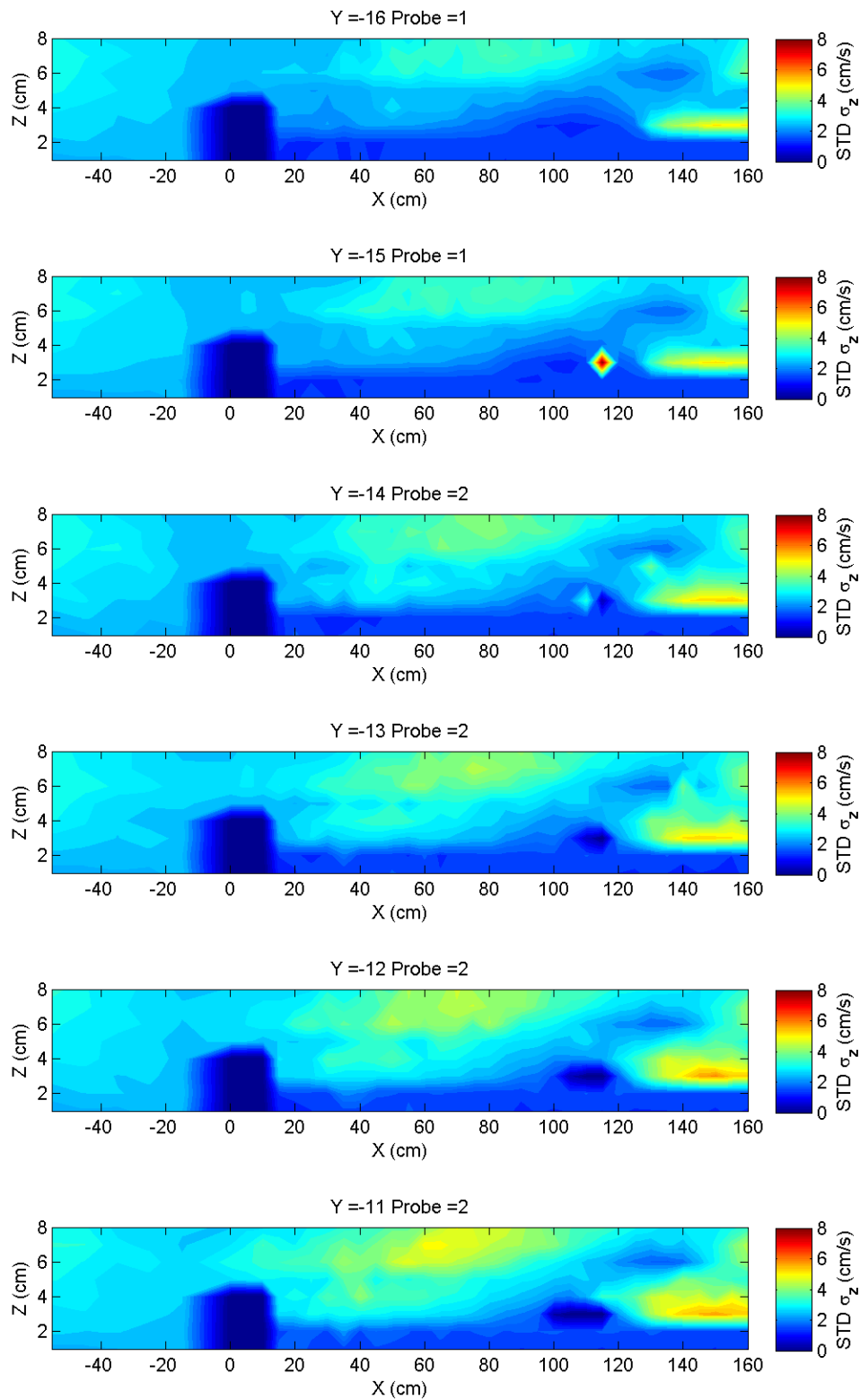


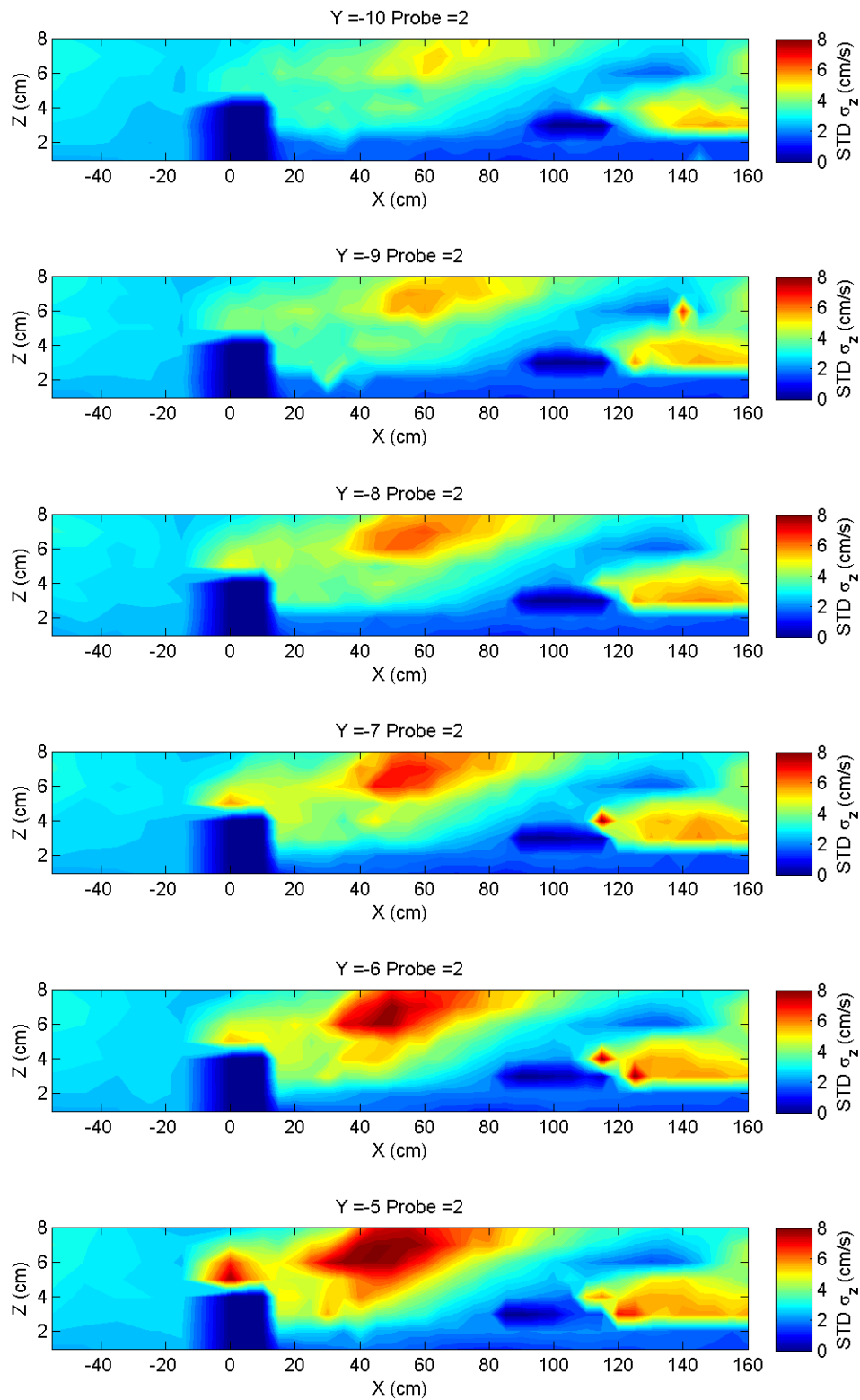
## Standard Deviation $\sigma_z$ in x and z-Directions

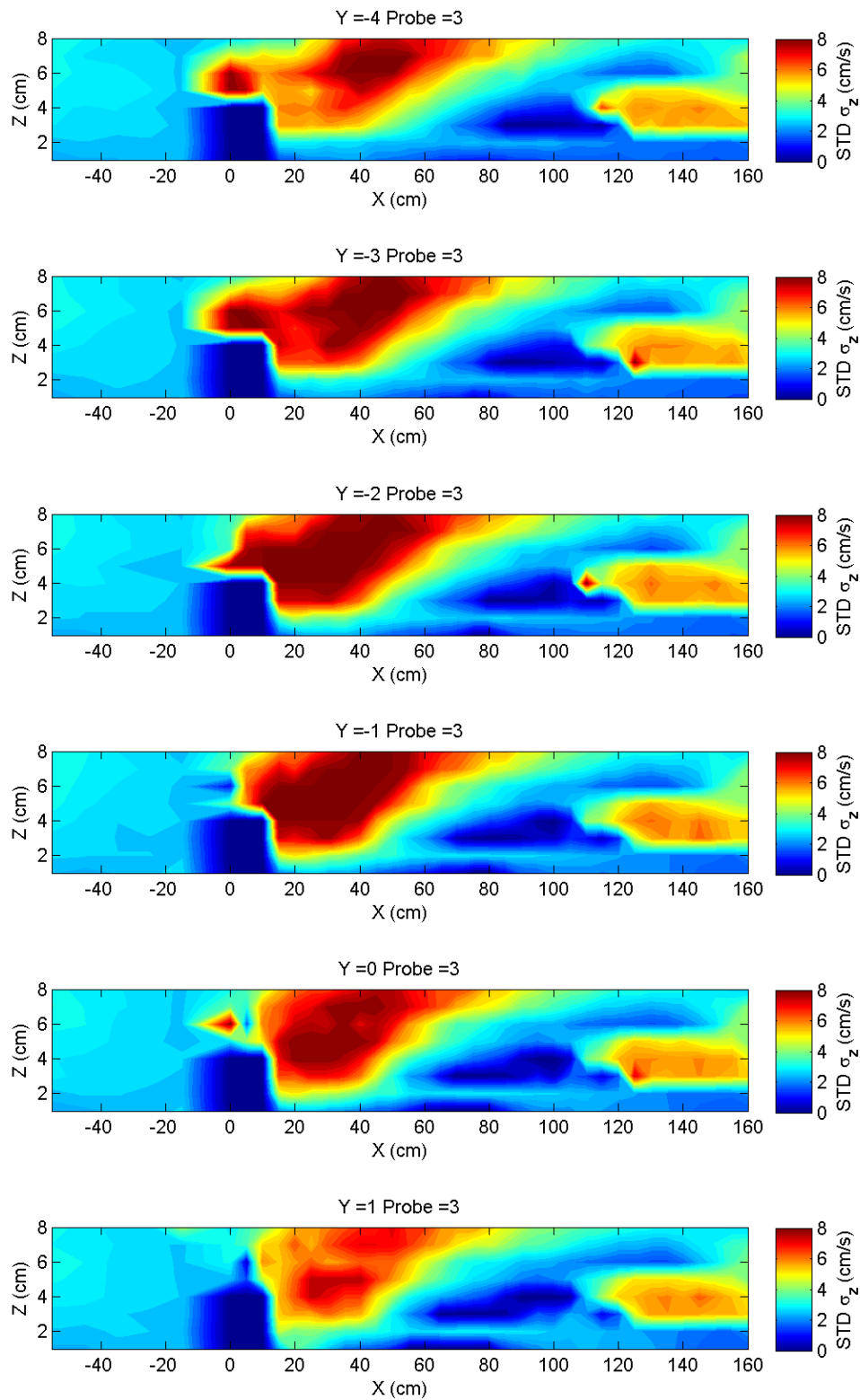




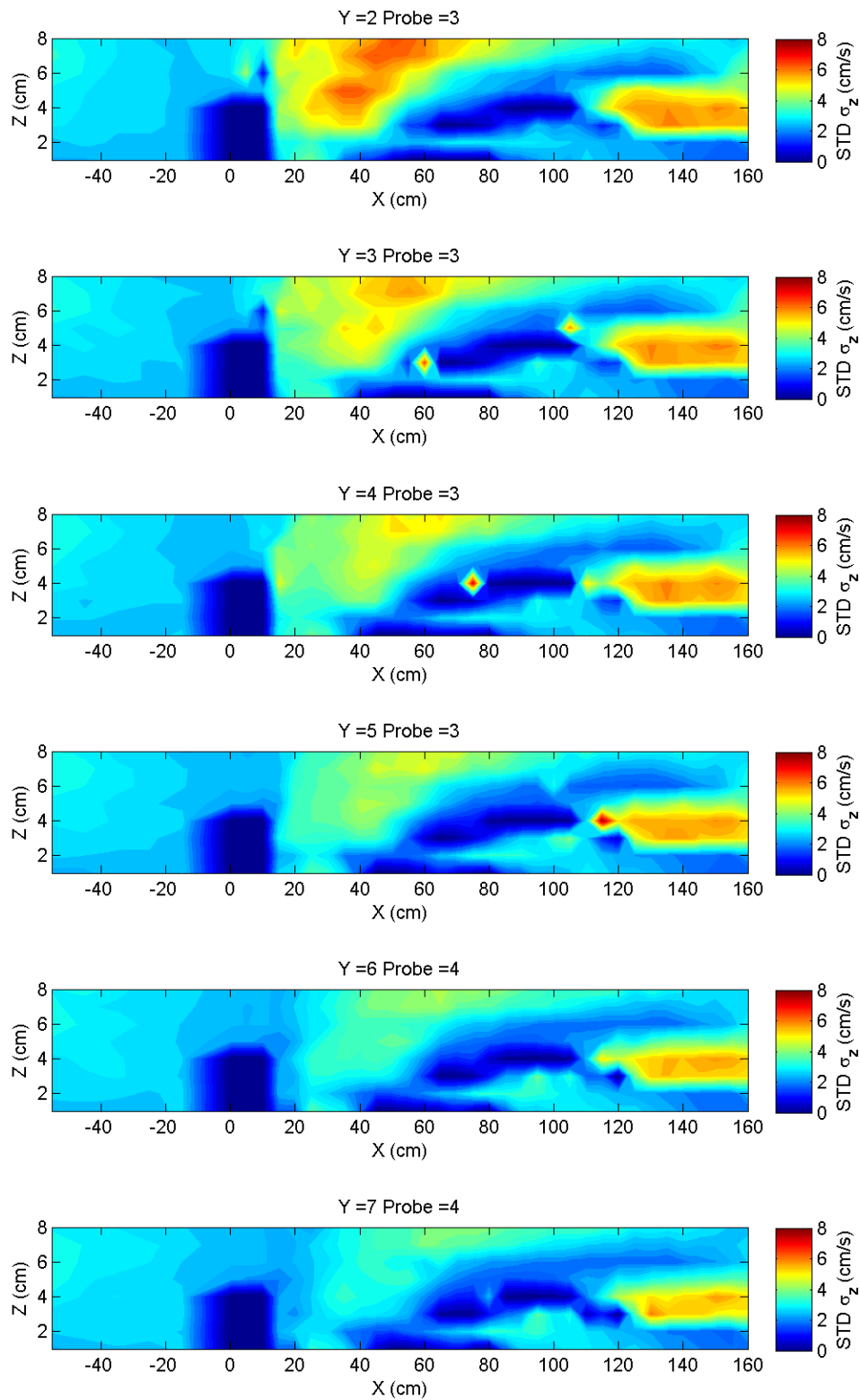


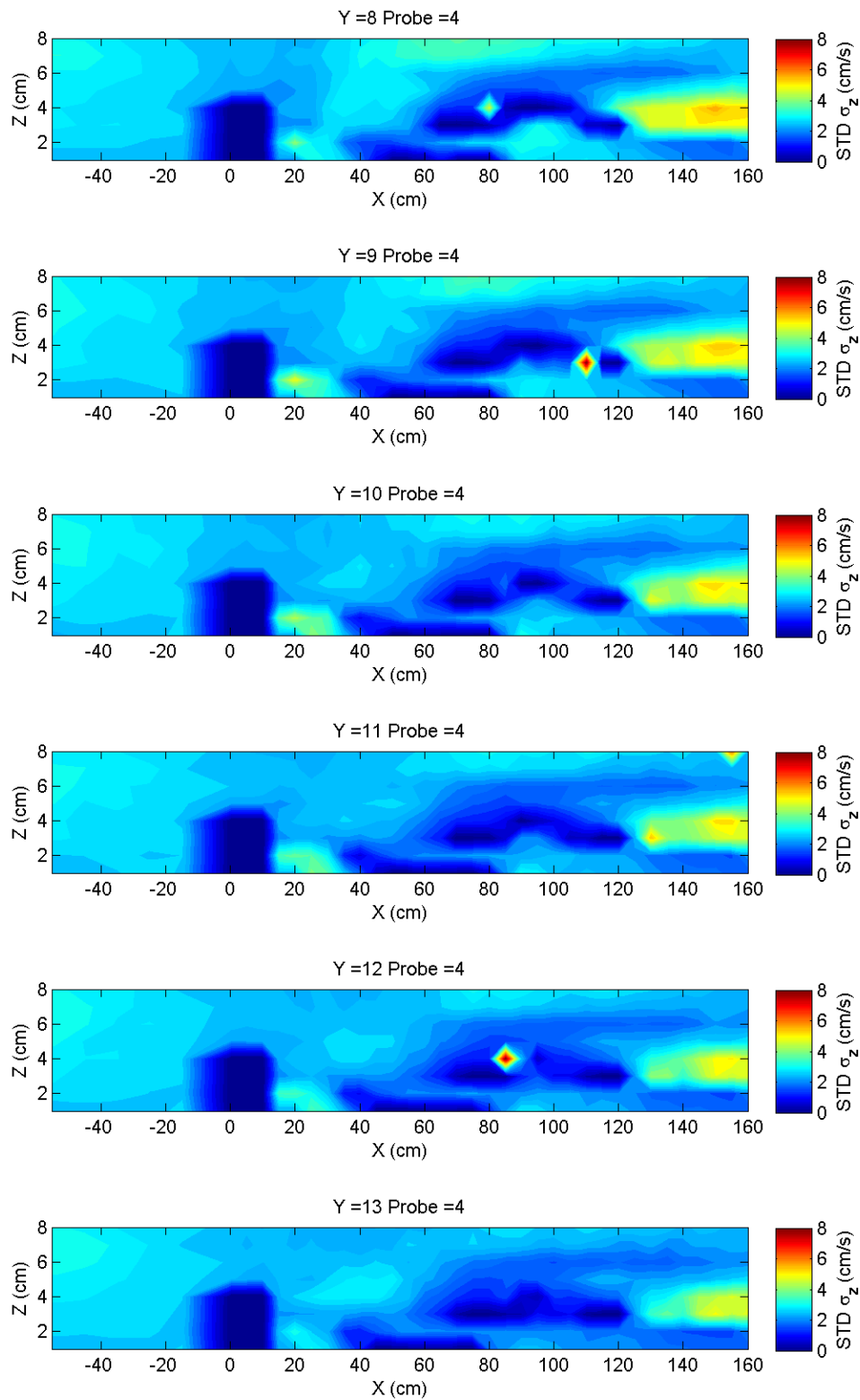


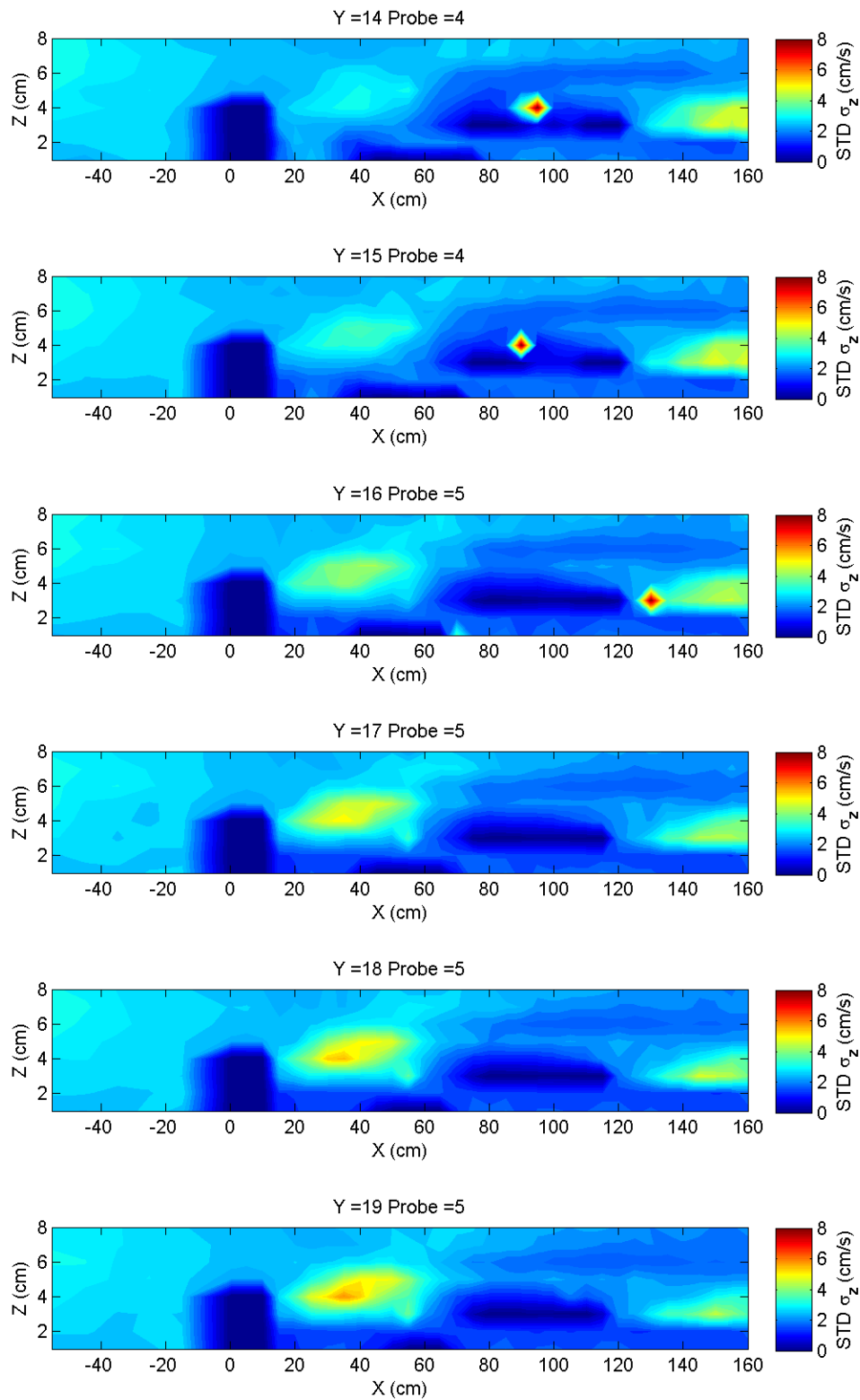


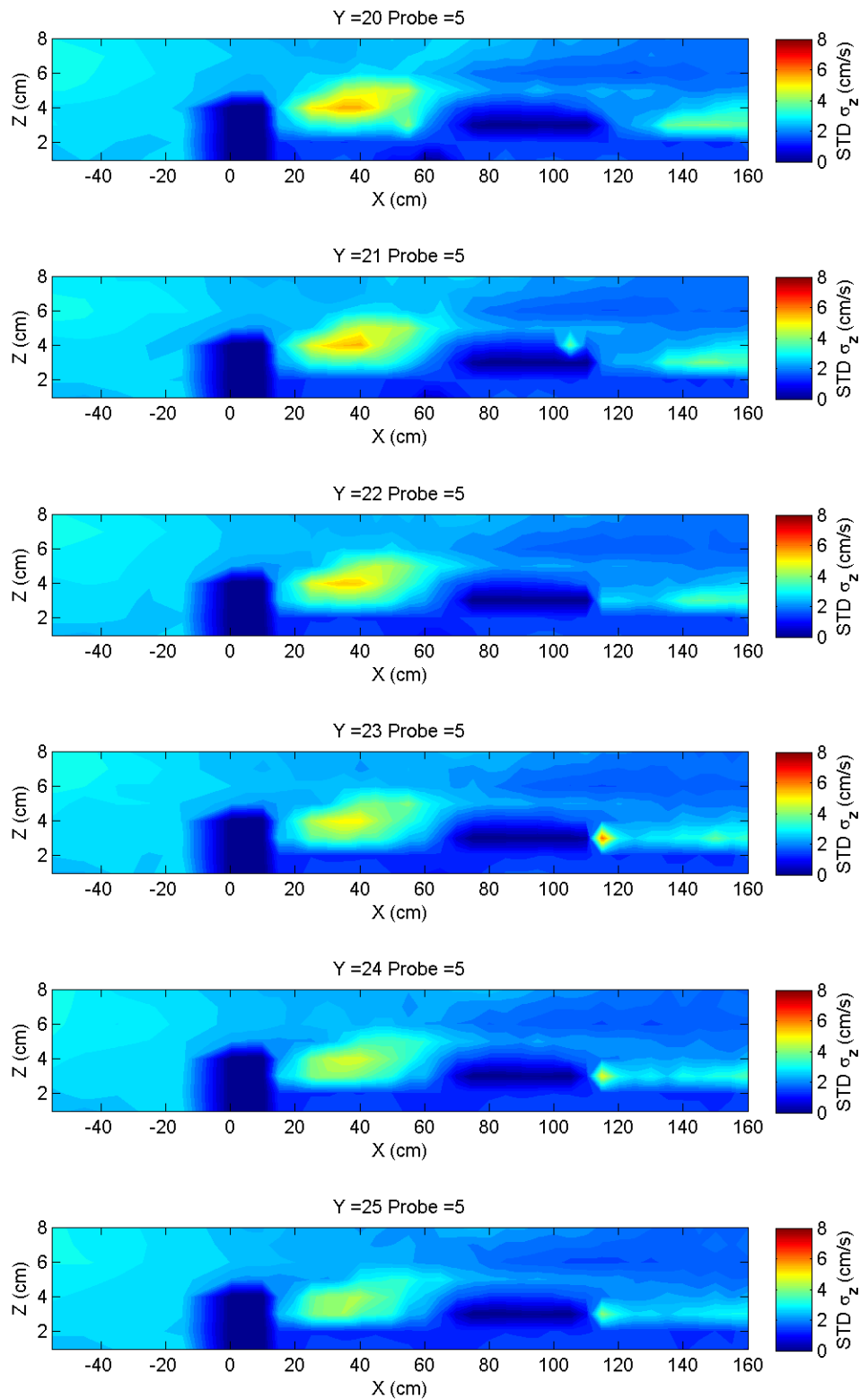


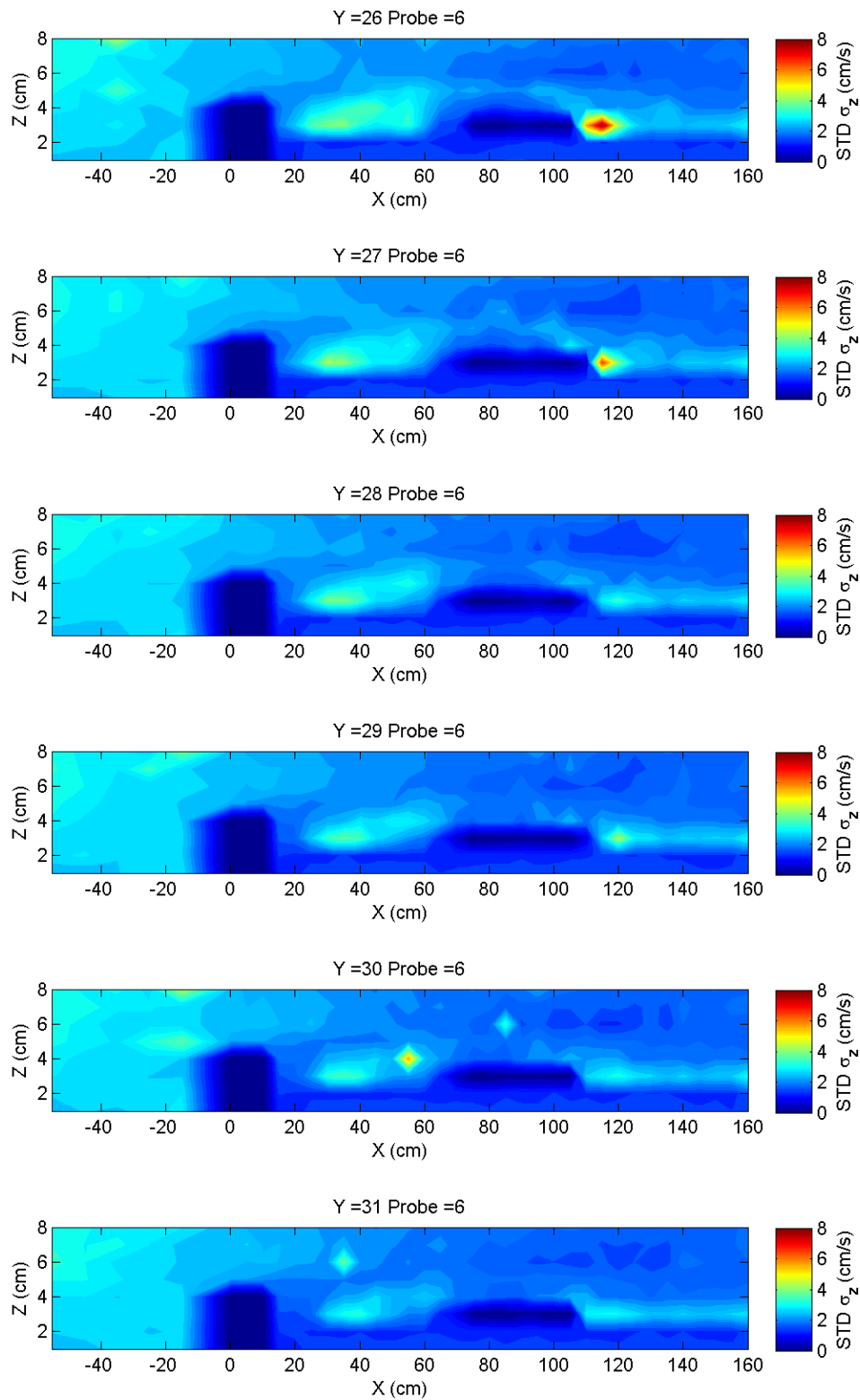


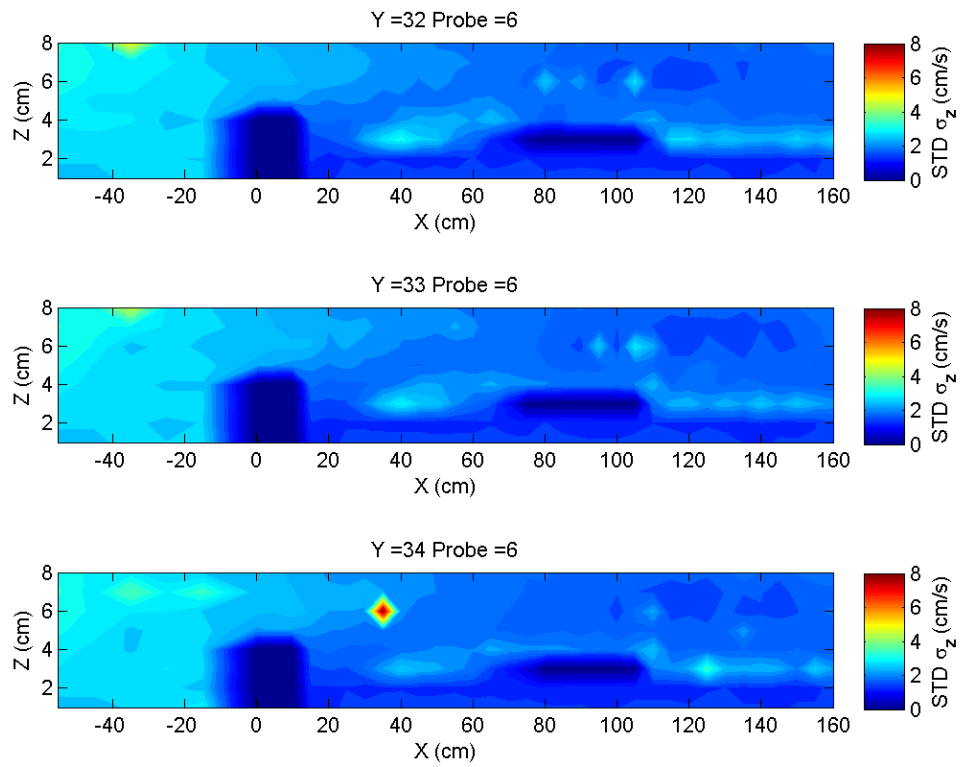






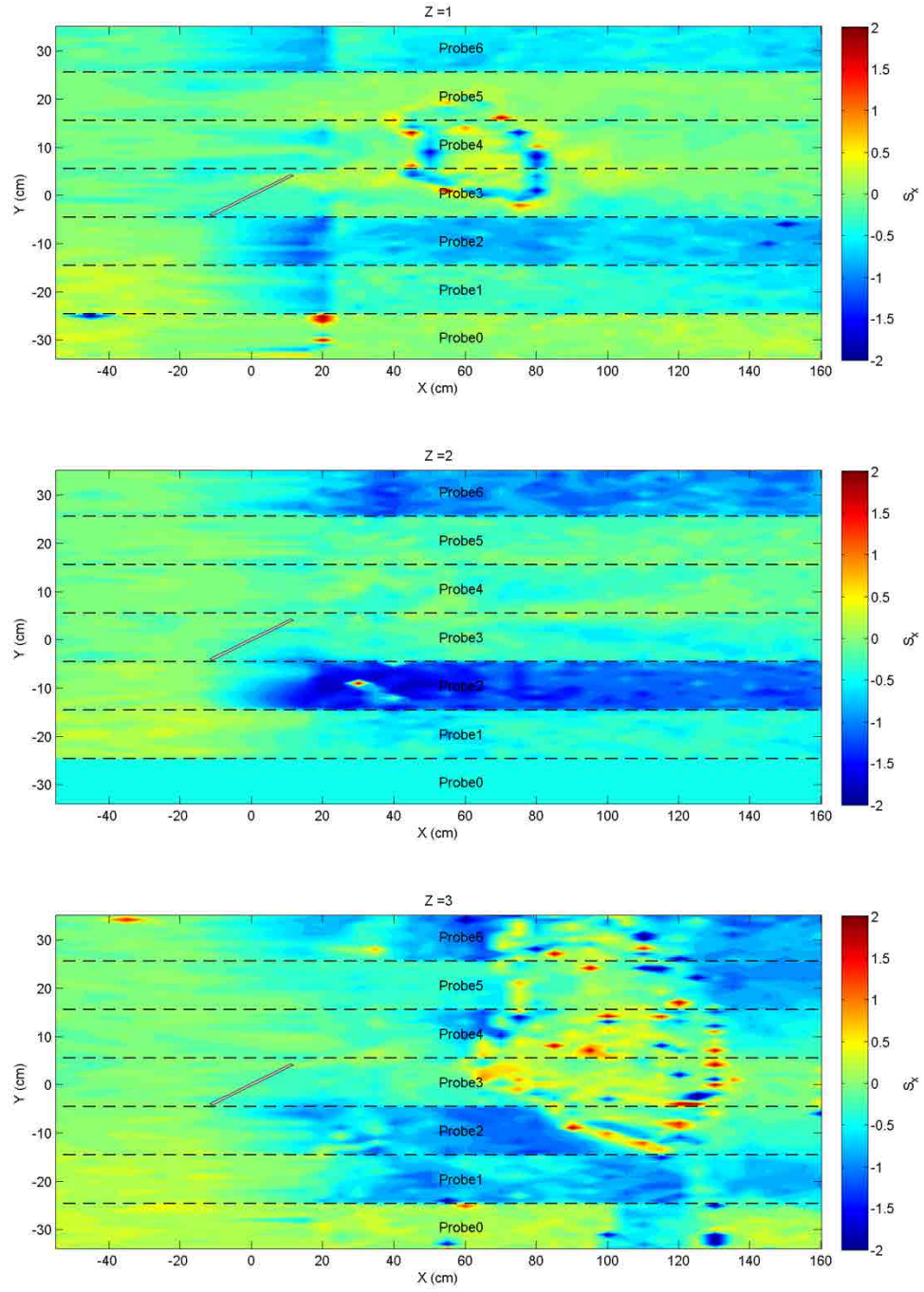




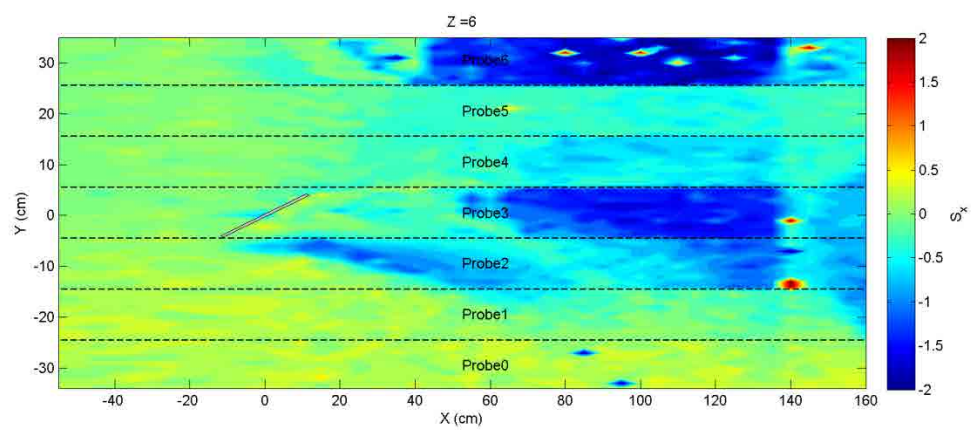
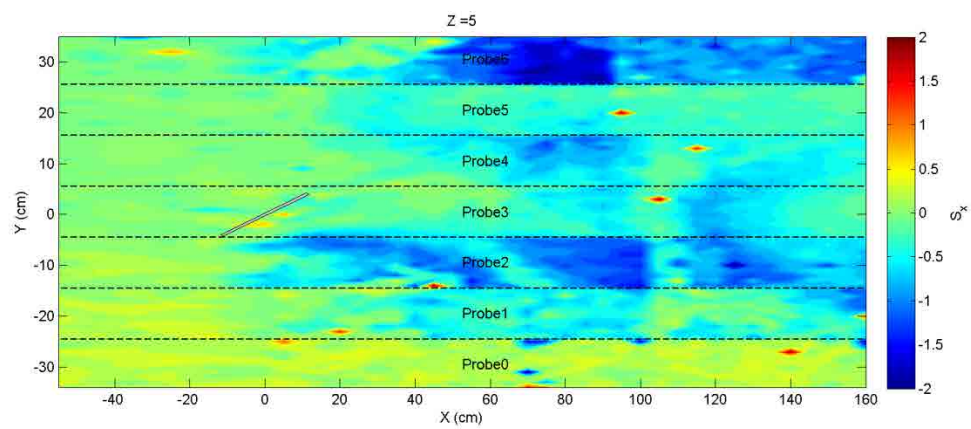
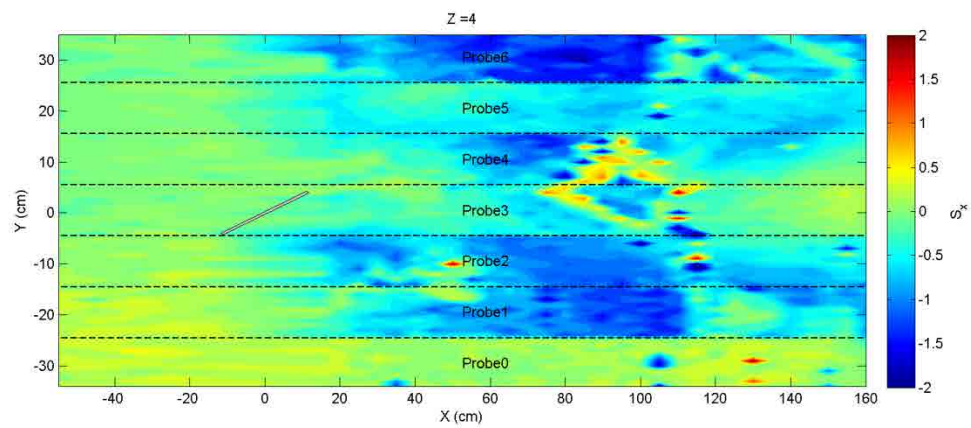


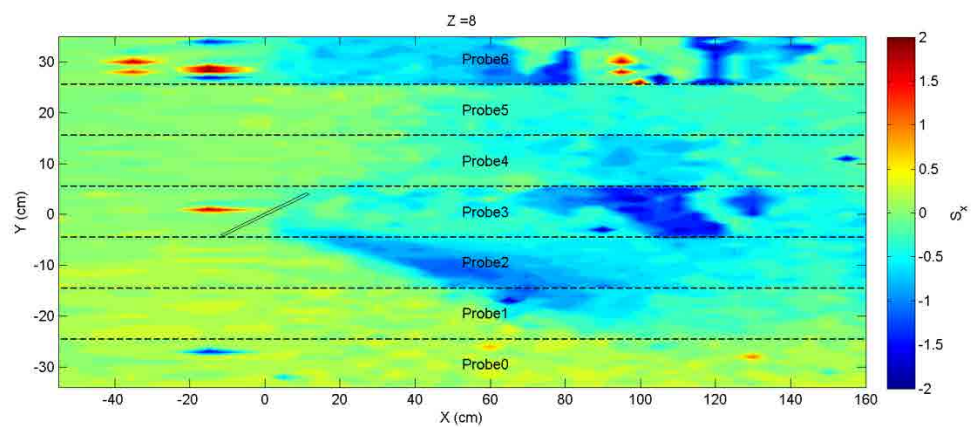
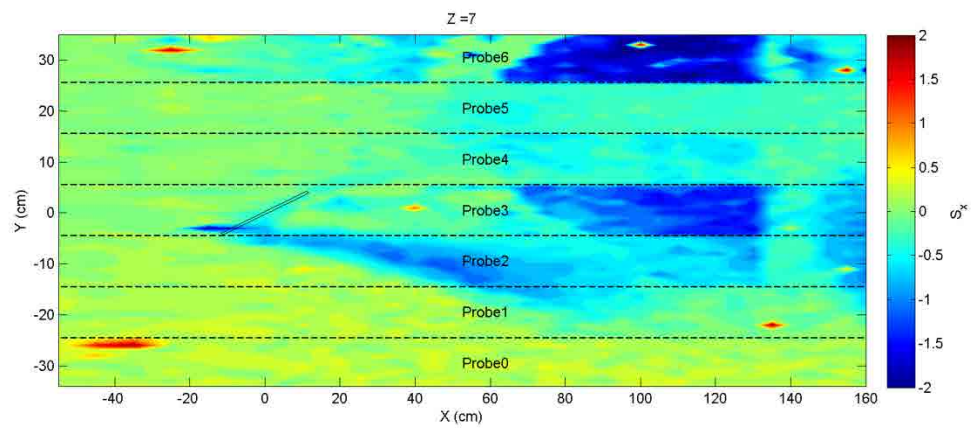
## 2. Skewness Factor

### Skewness Factor $S_x$ in x and y-Directions

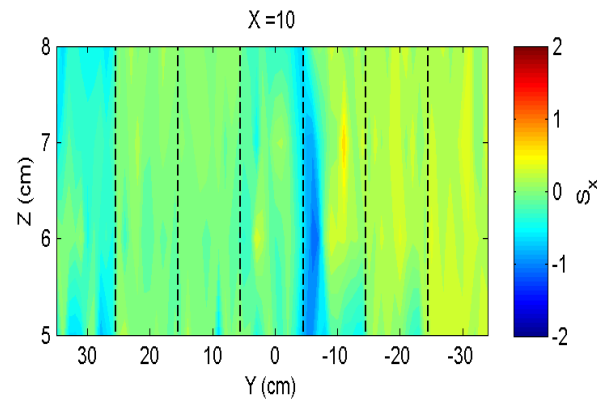
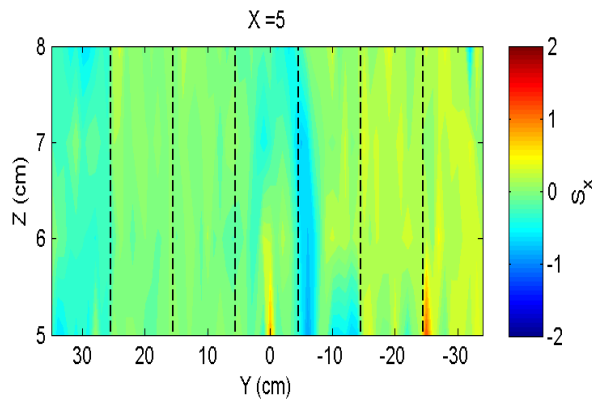
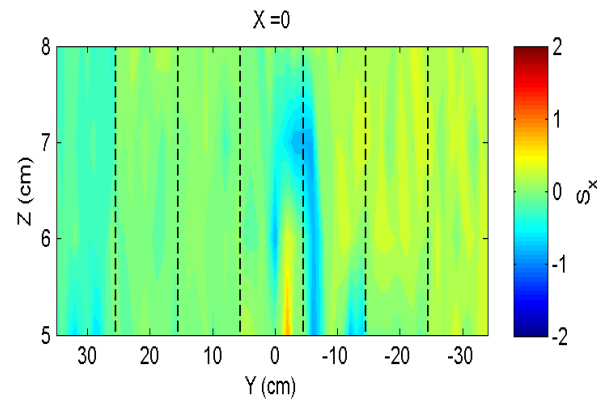
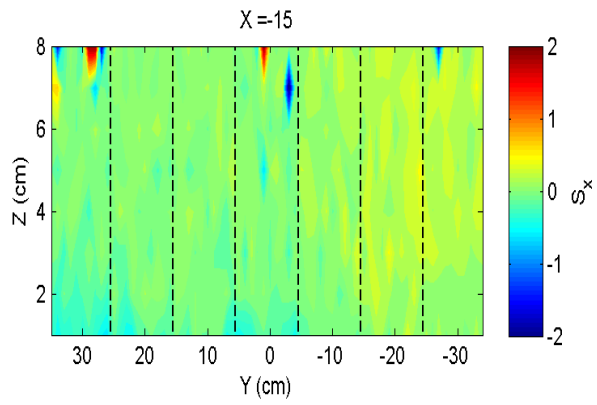
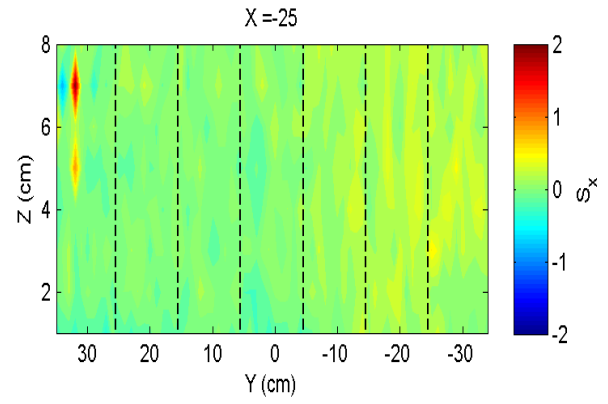
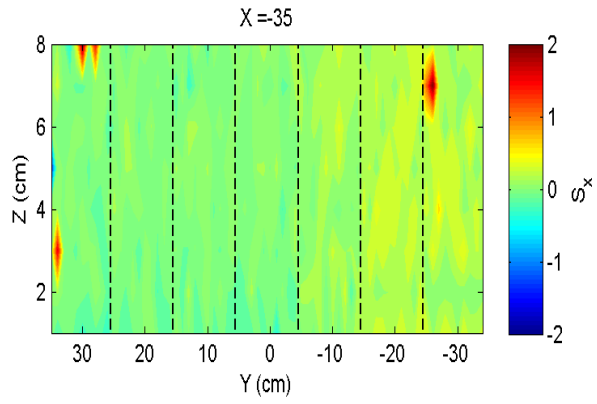
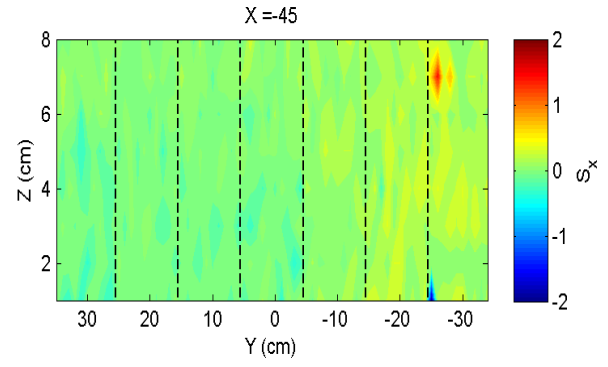
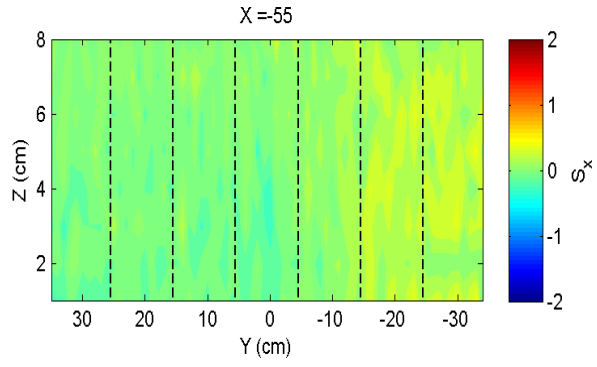


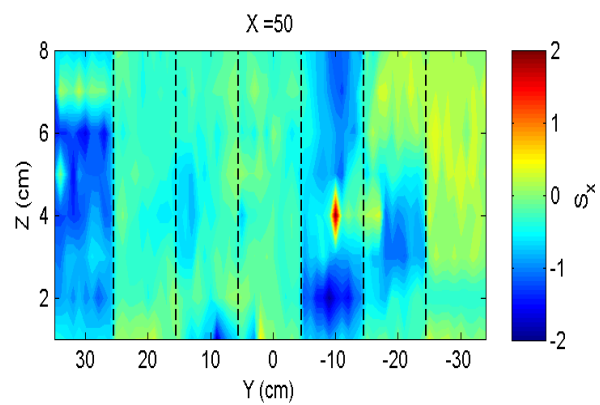
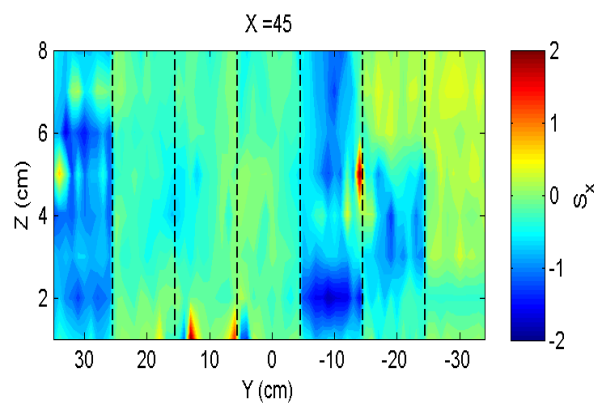
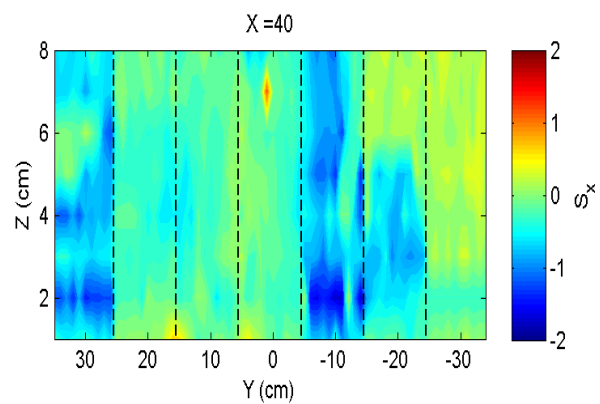
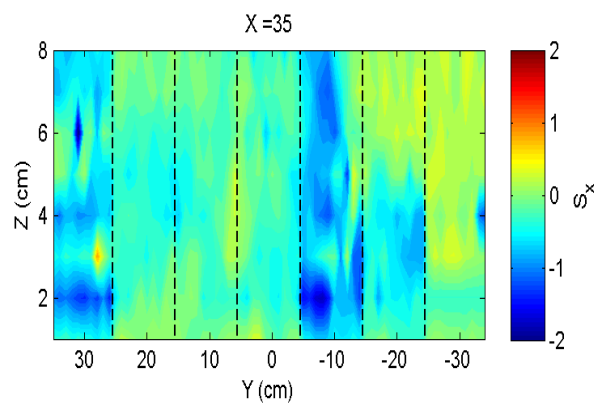
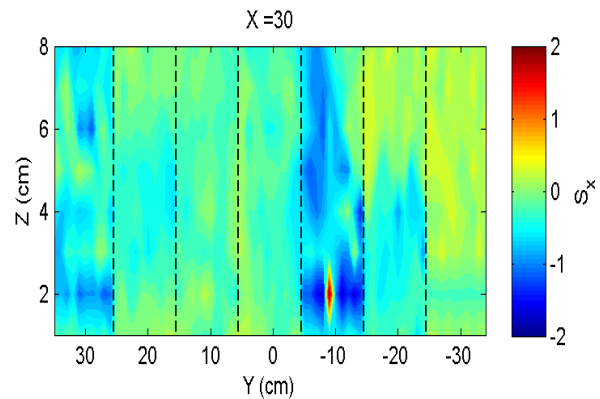
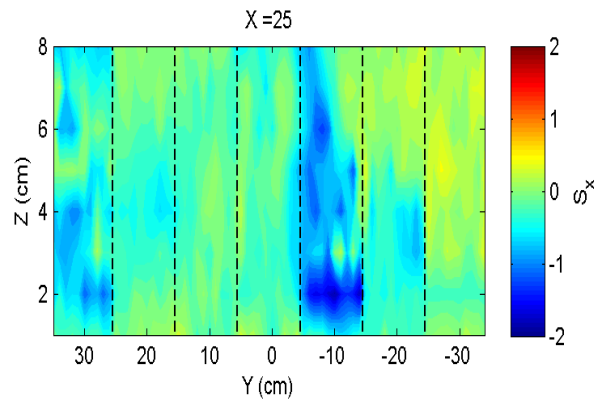
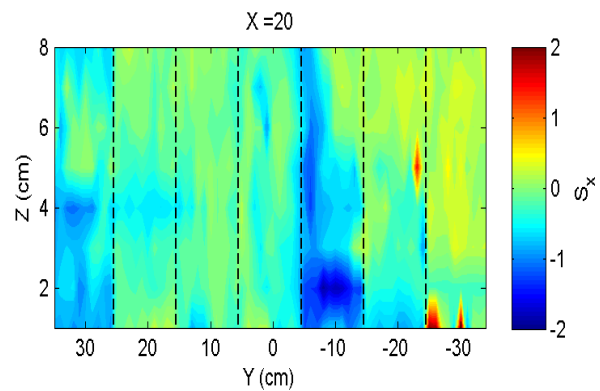
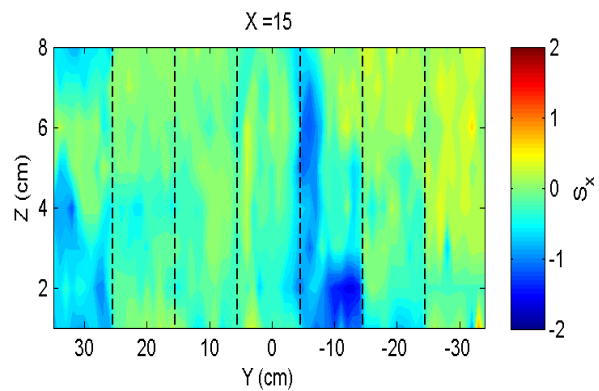


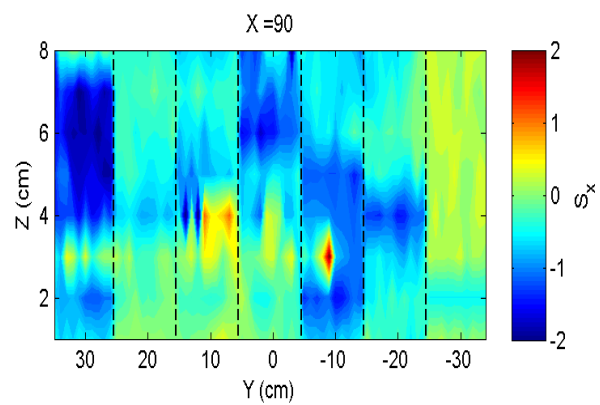
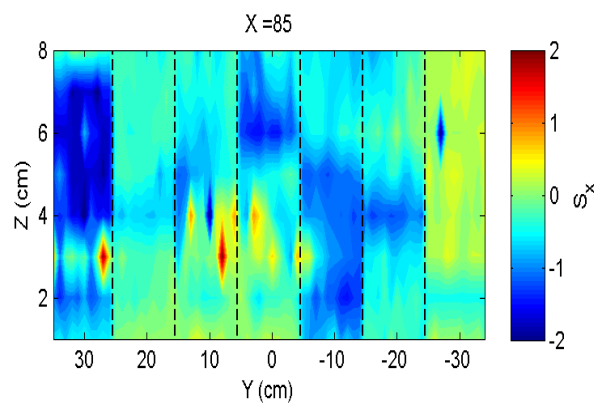
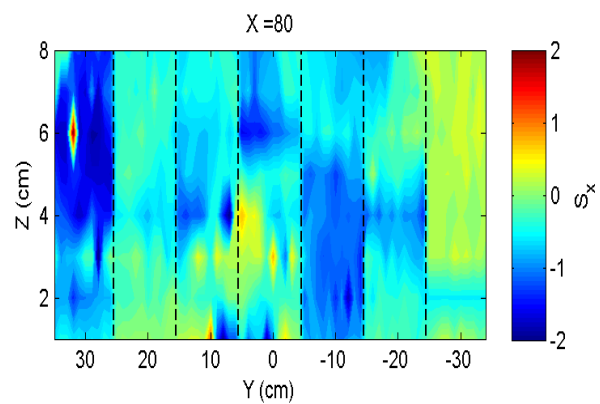
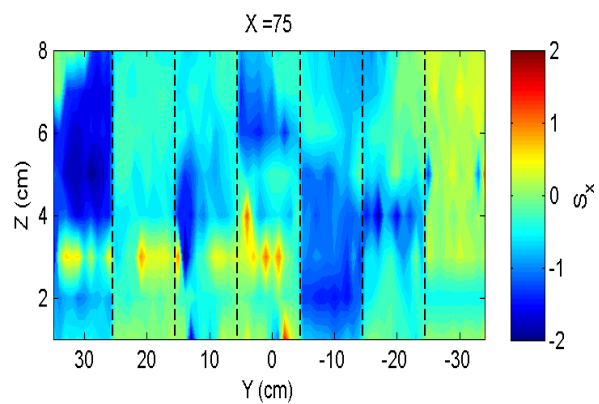
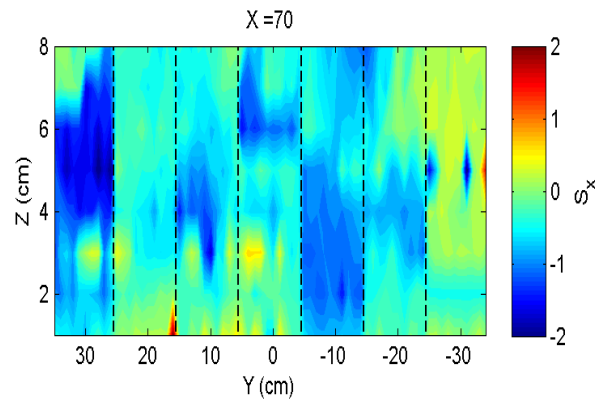
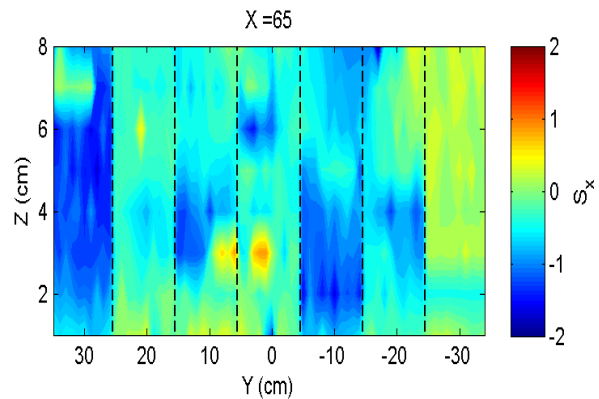
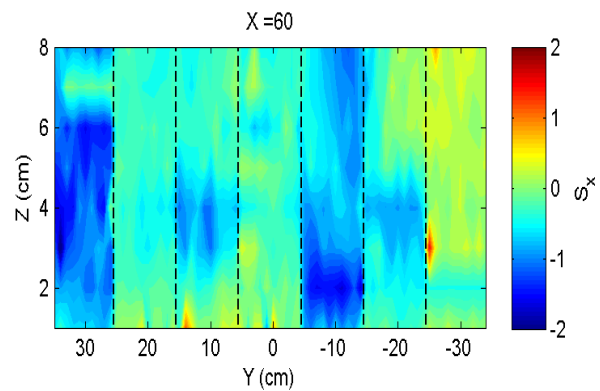
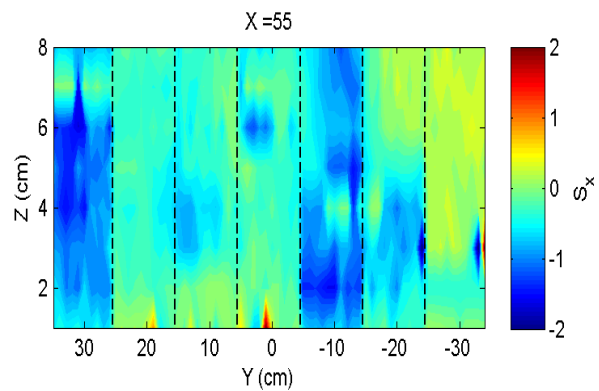




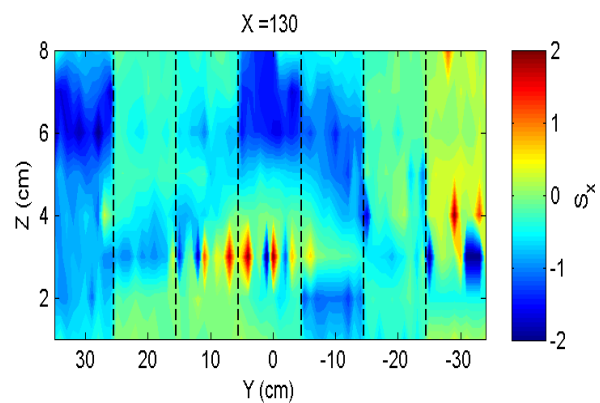
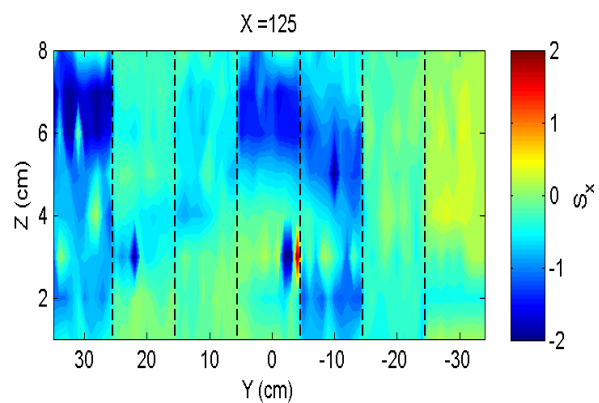
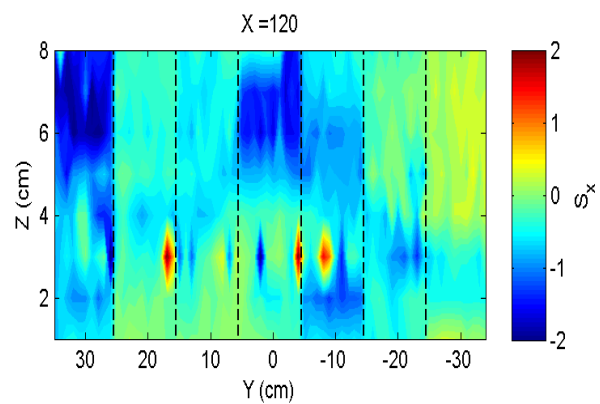
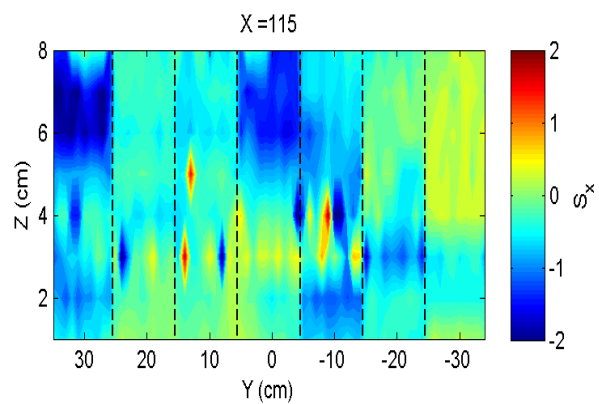
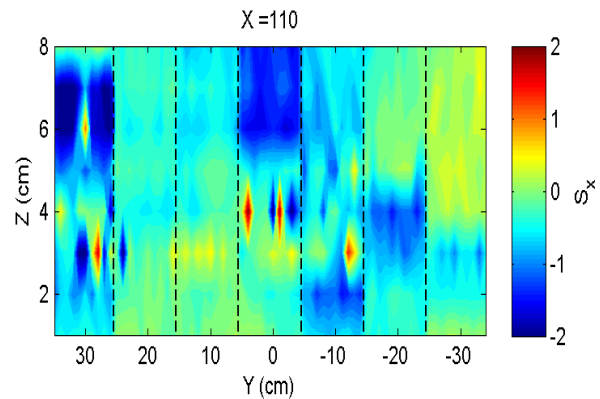
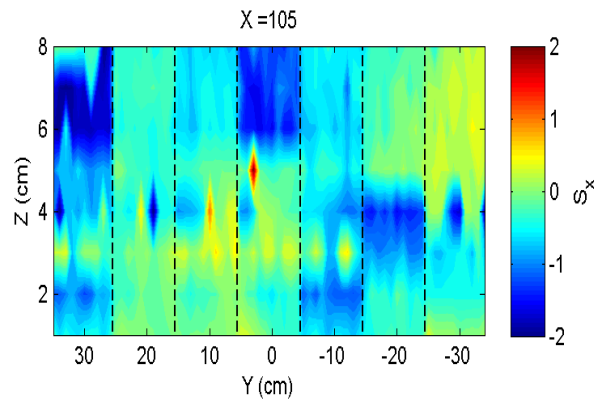
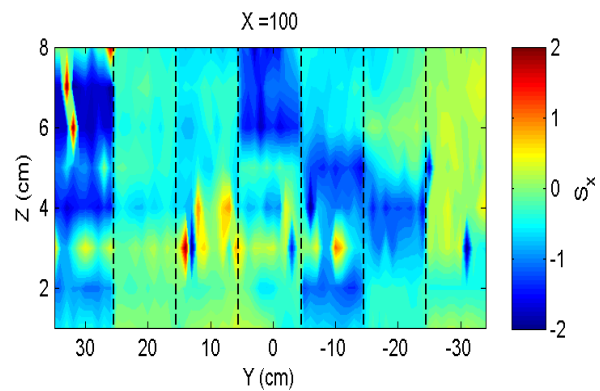
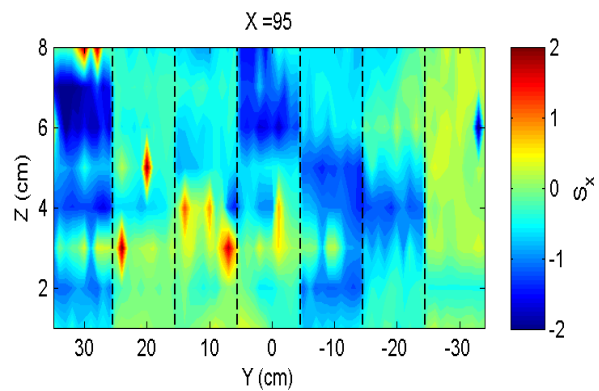
### Skewness Factor $S_x$ in y and z-Directions

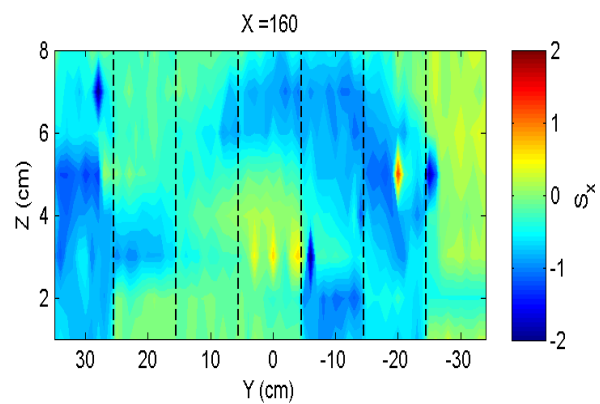
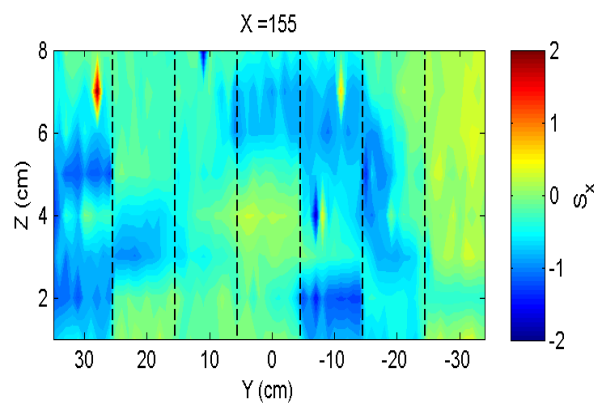
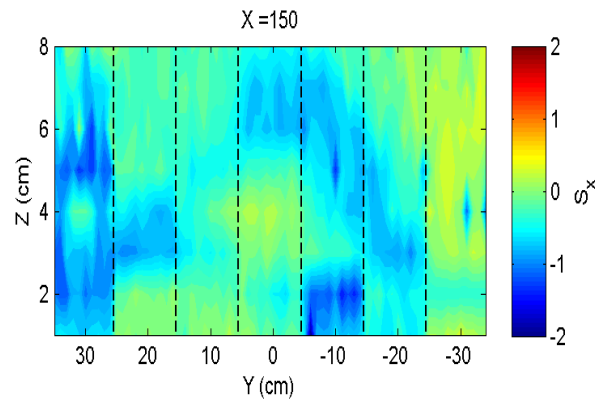
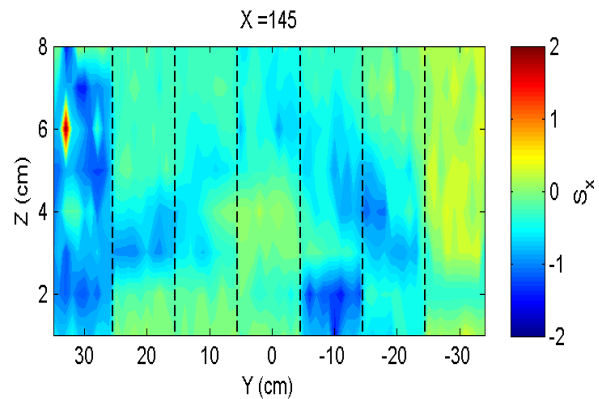
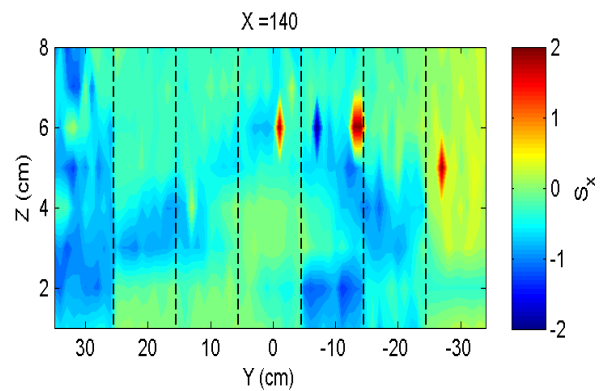
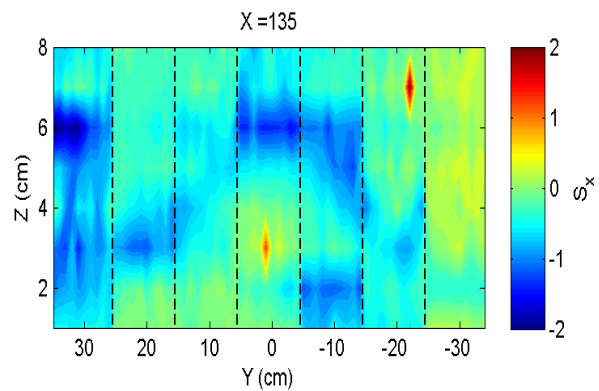




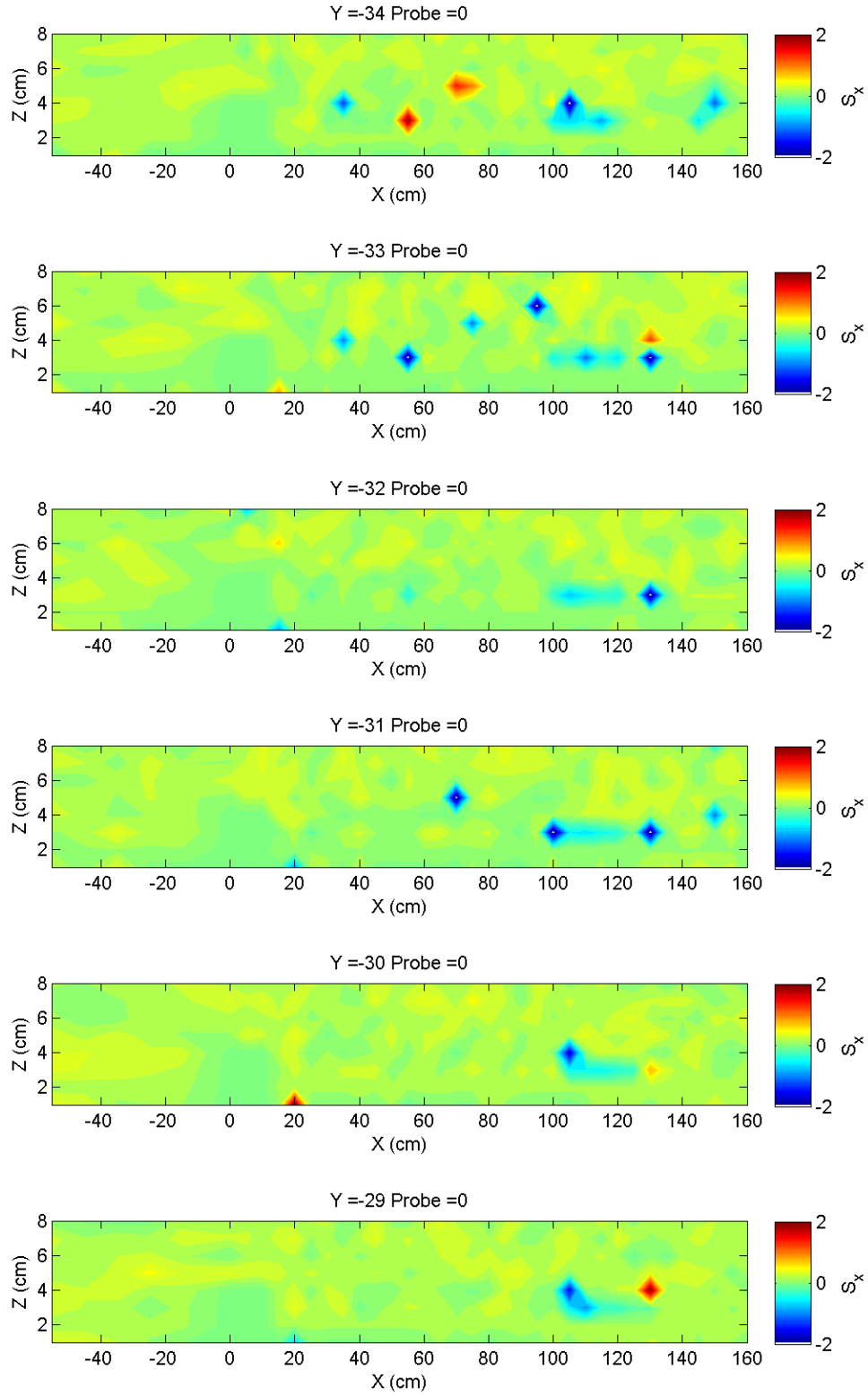




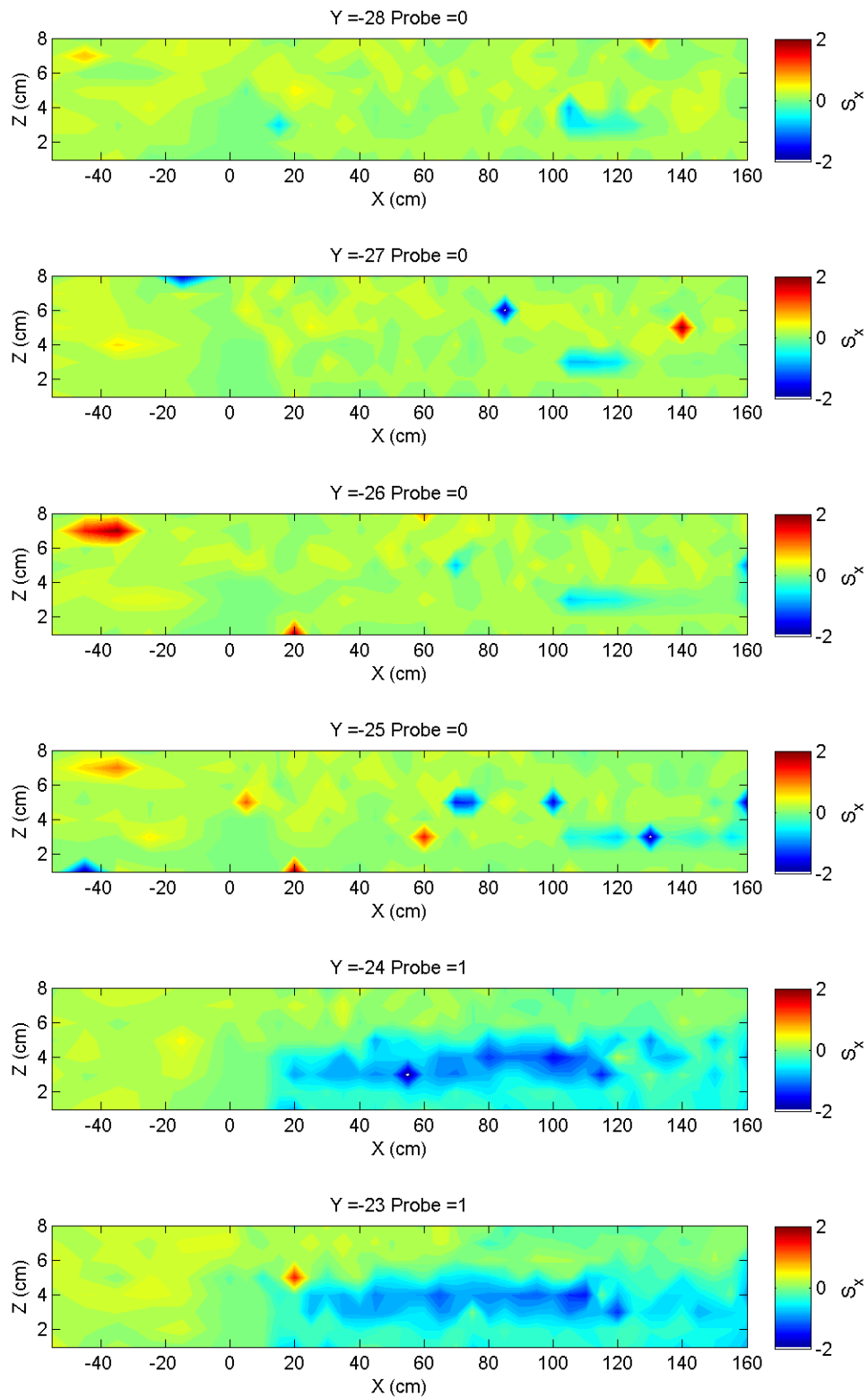


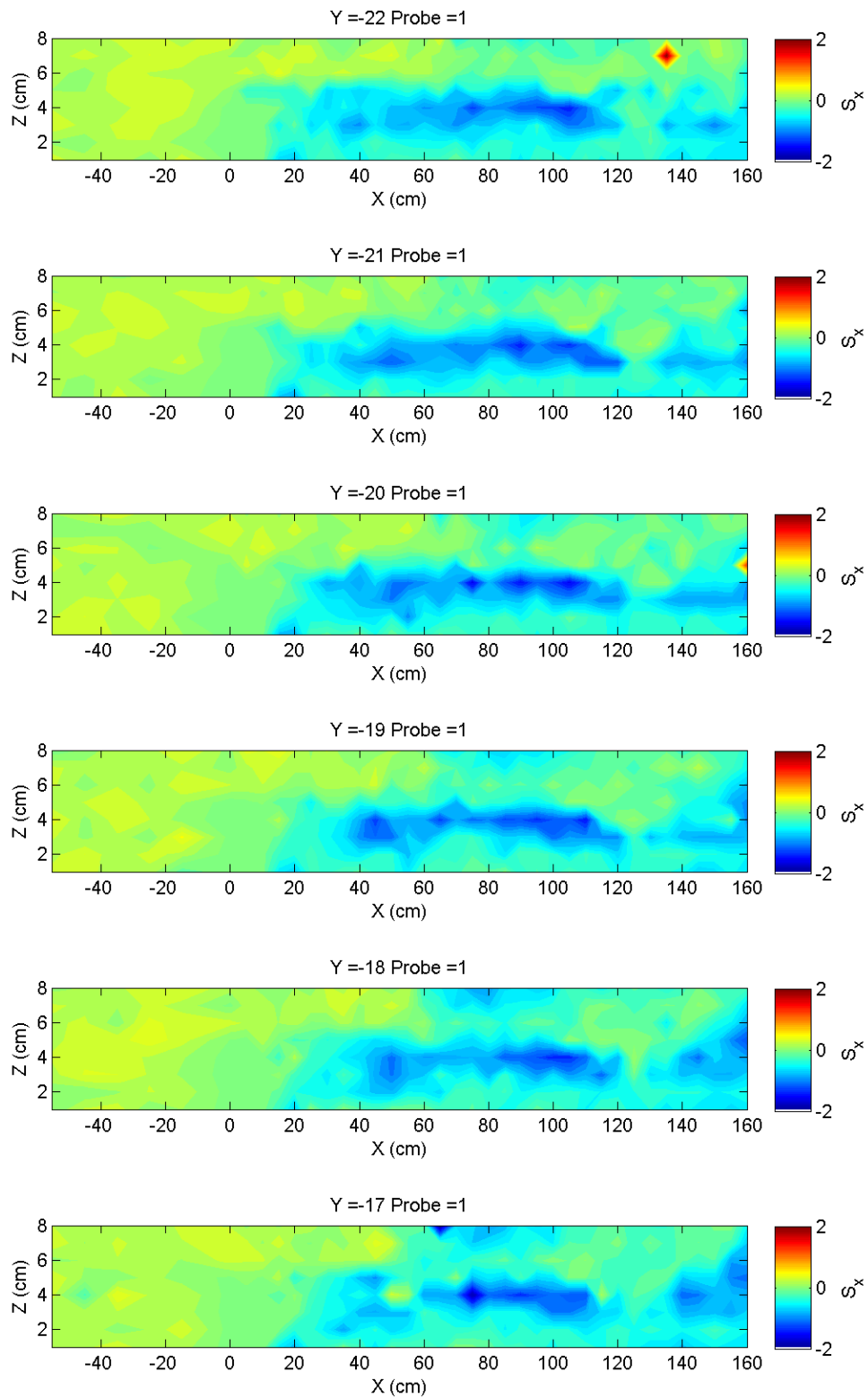


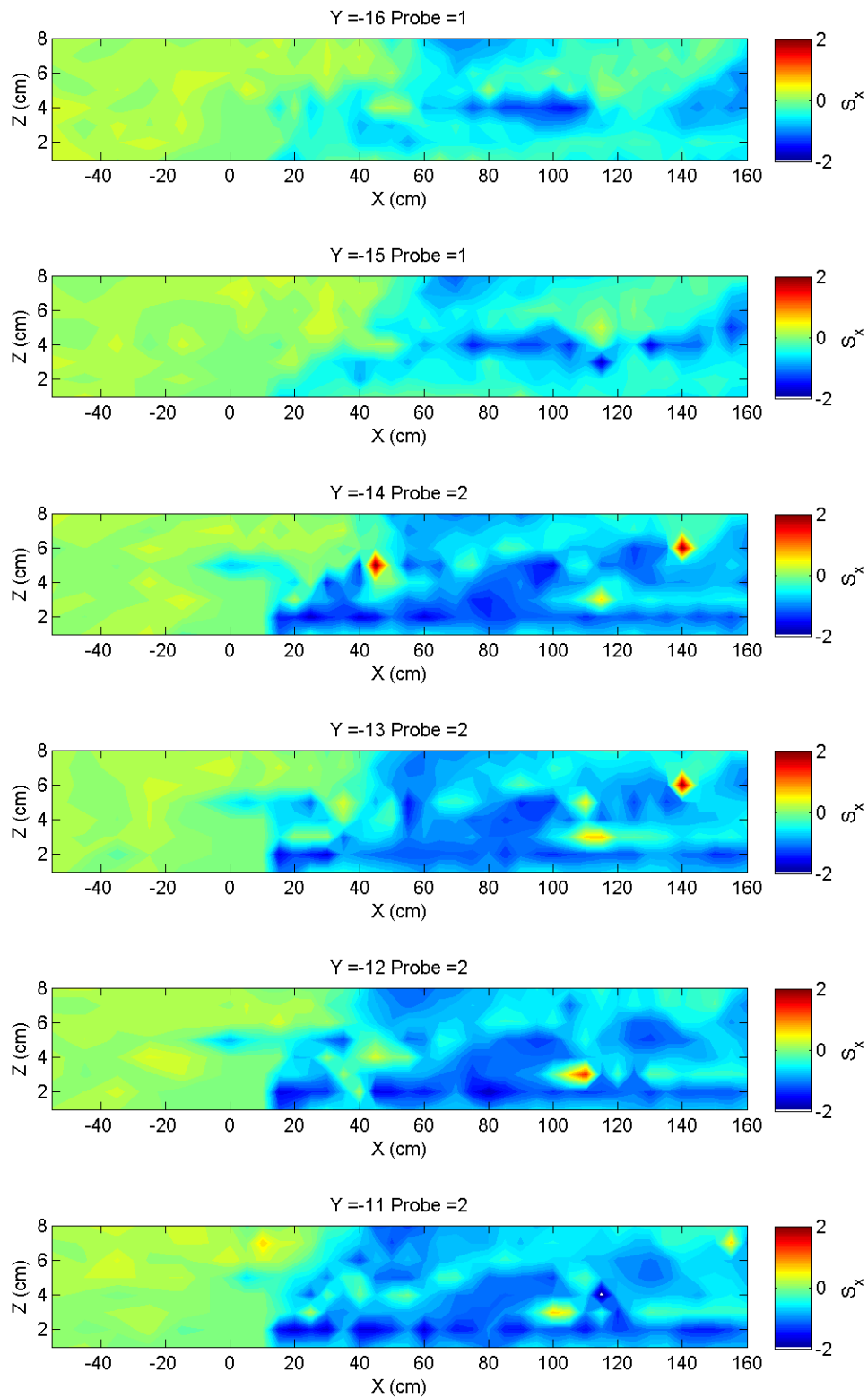
## Skewness Factor $S_x$ in x and z-Directions

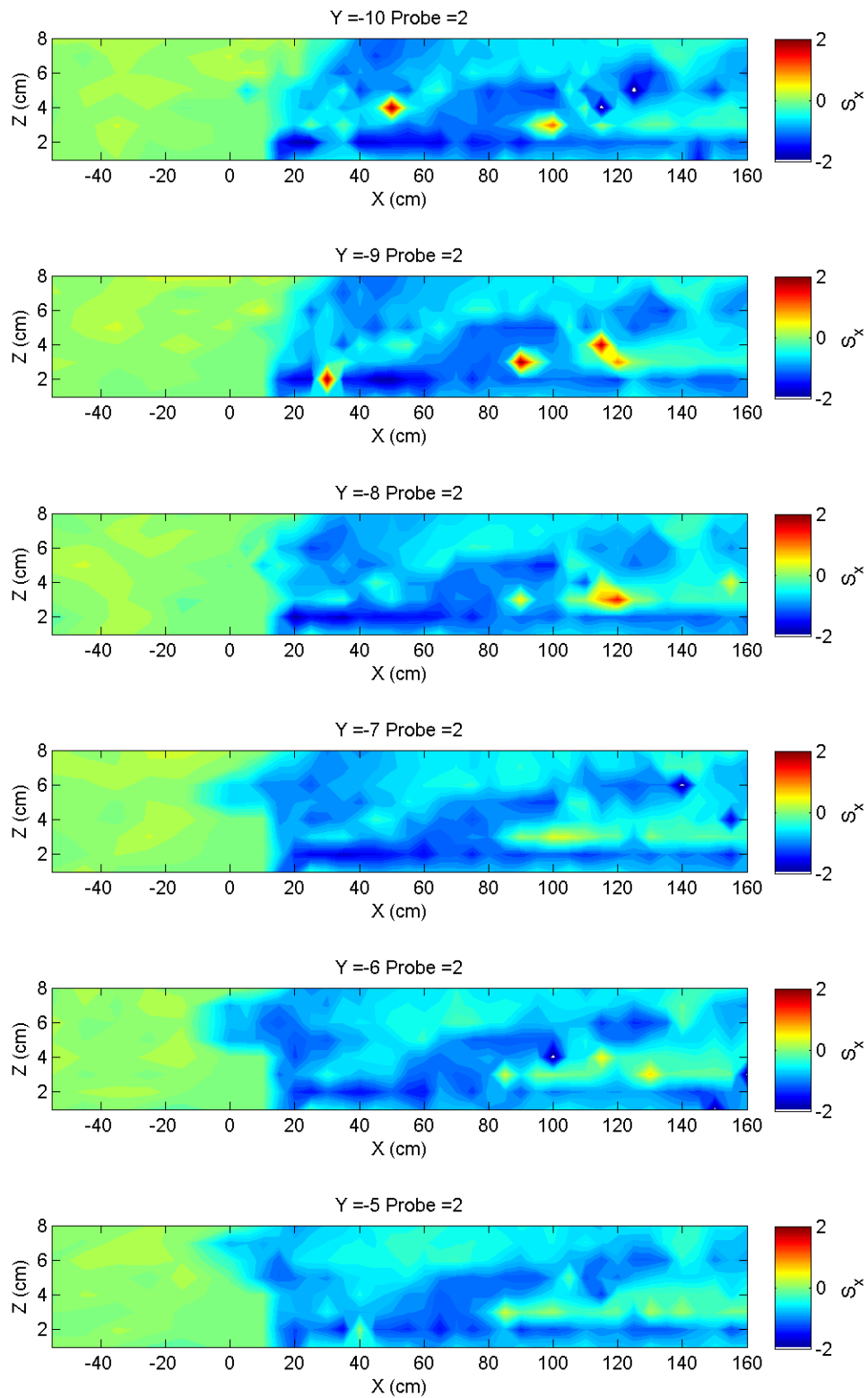


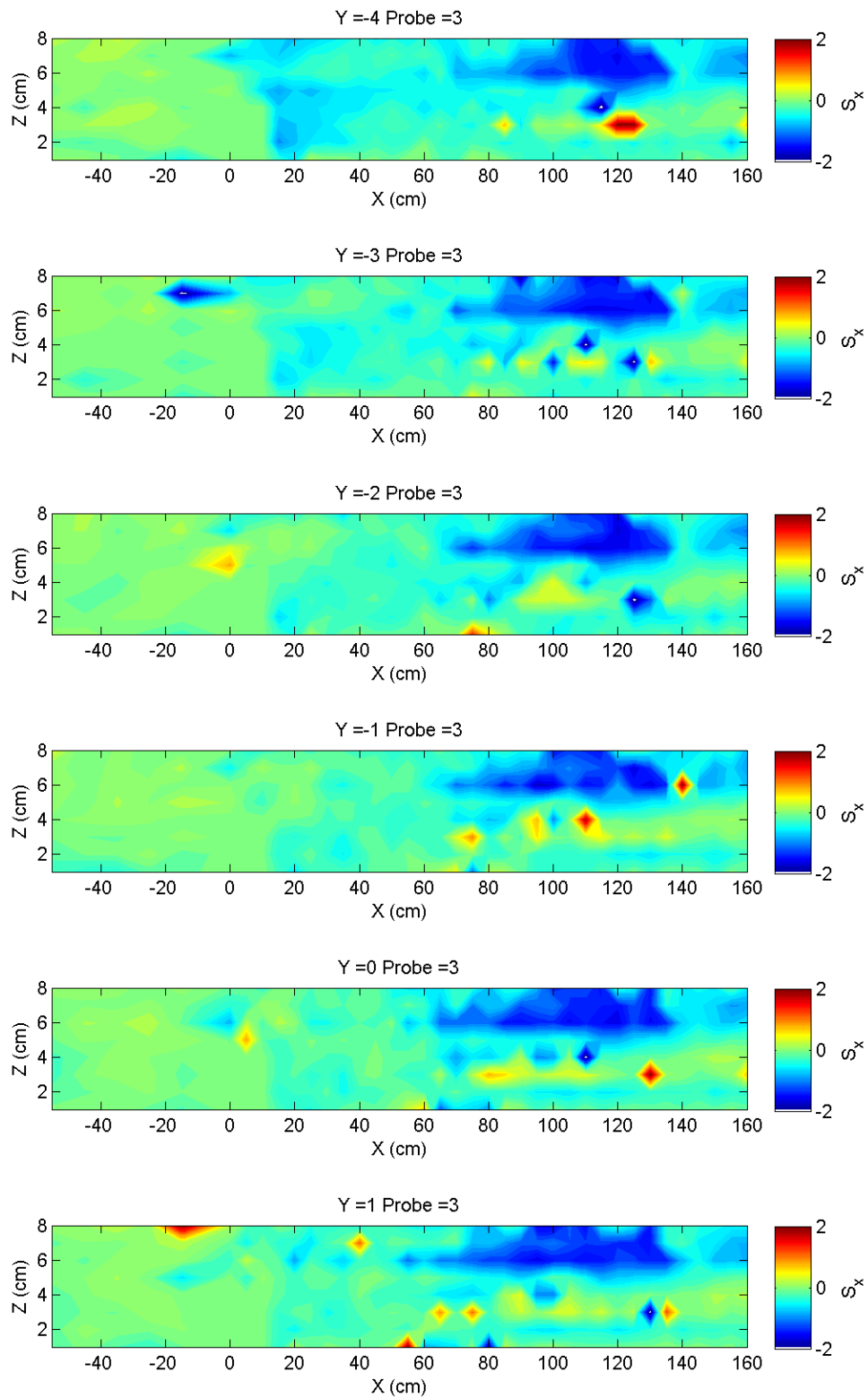


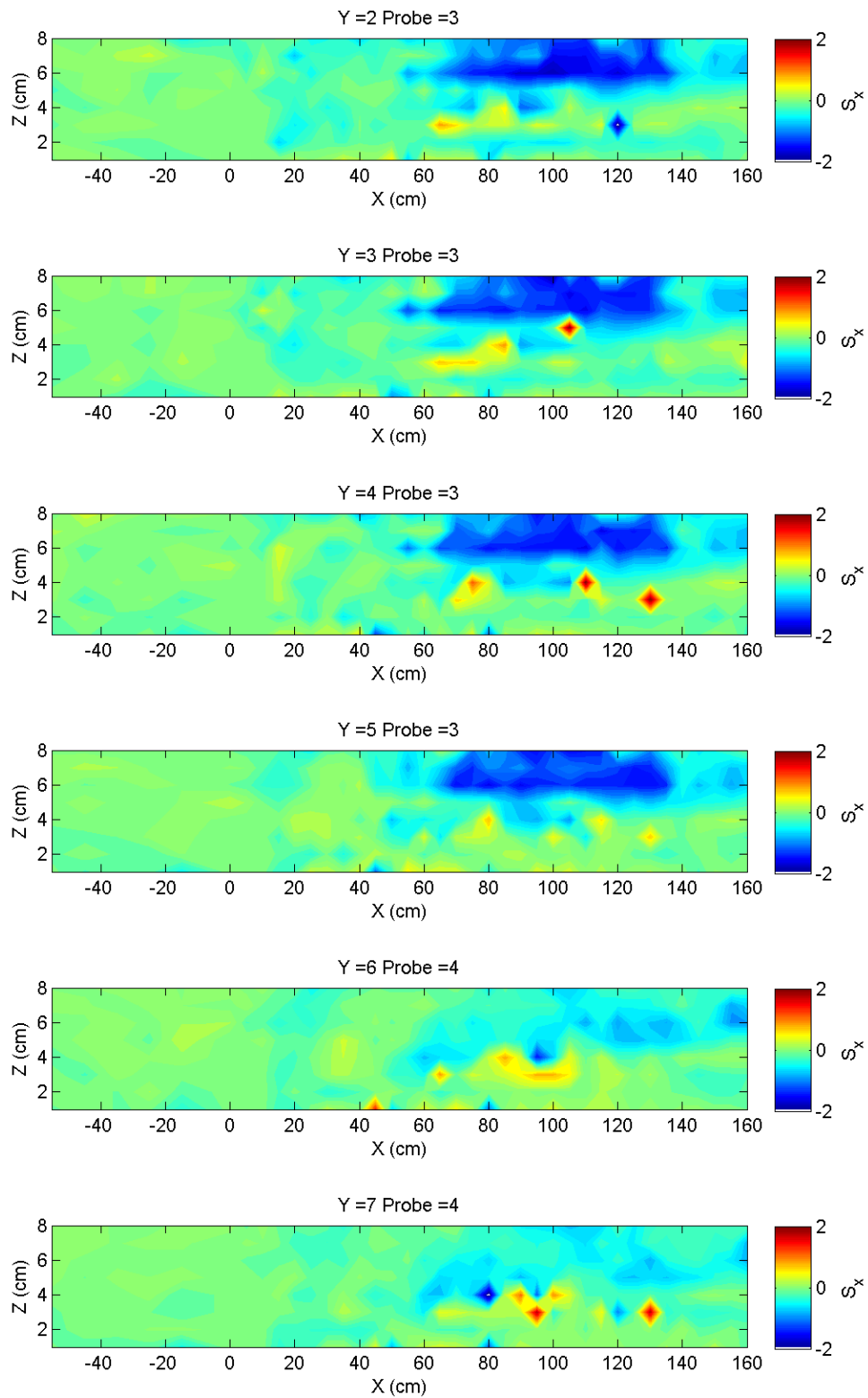


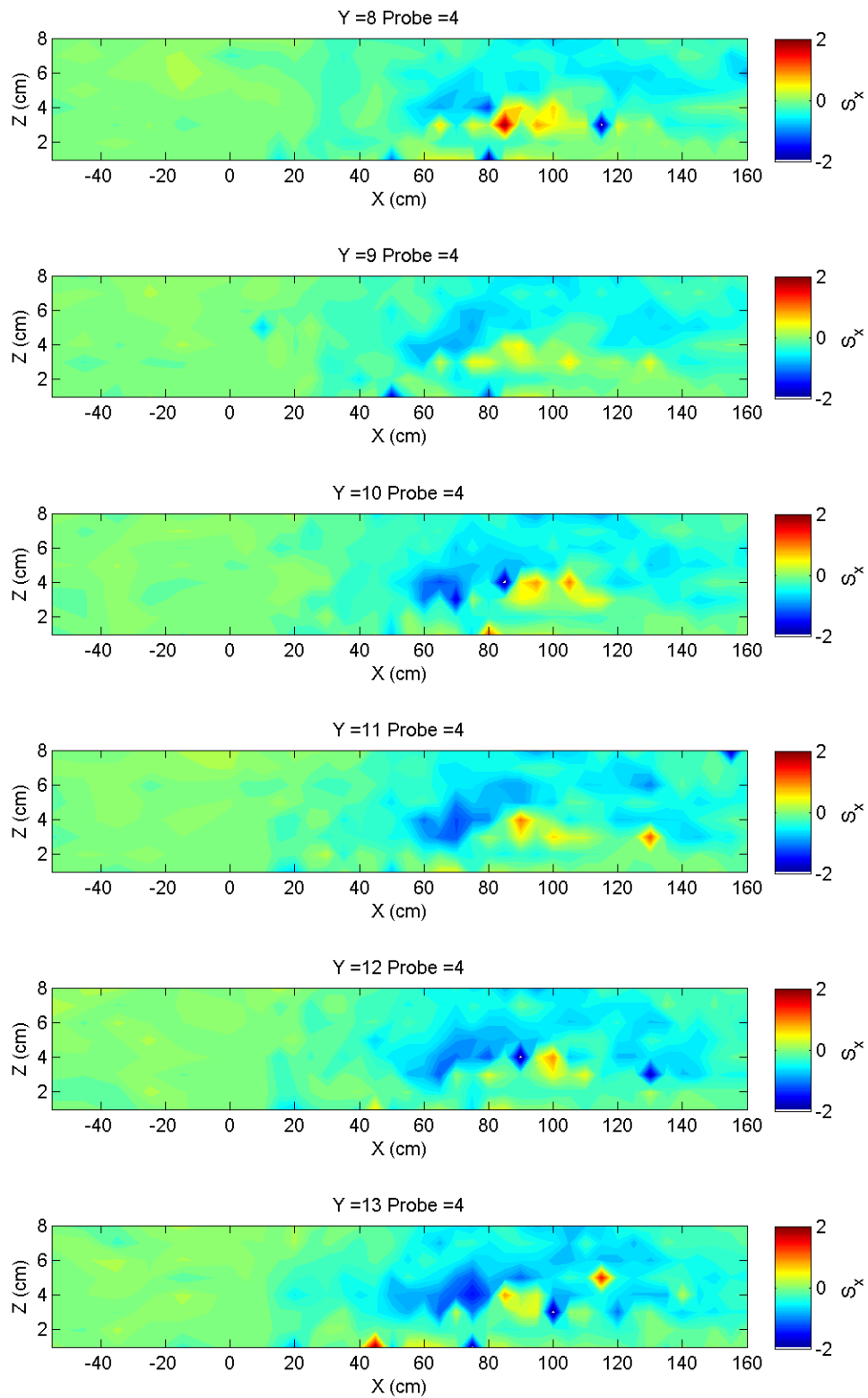


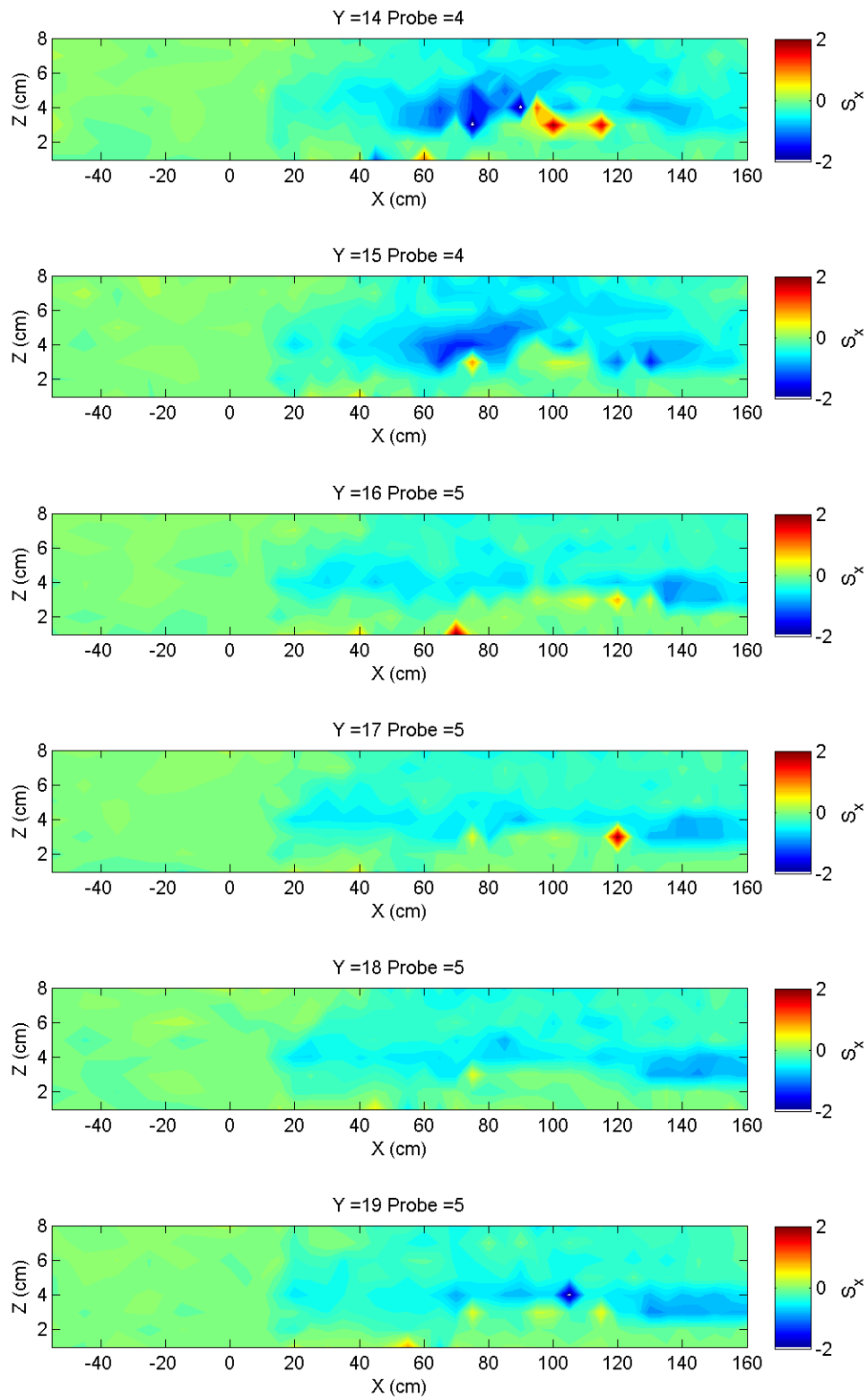




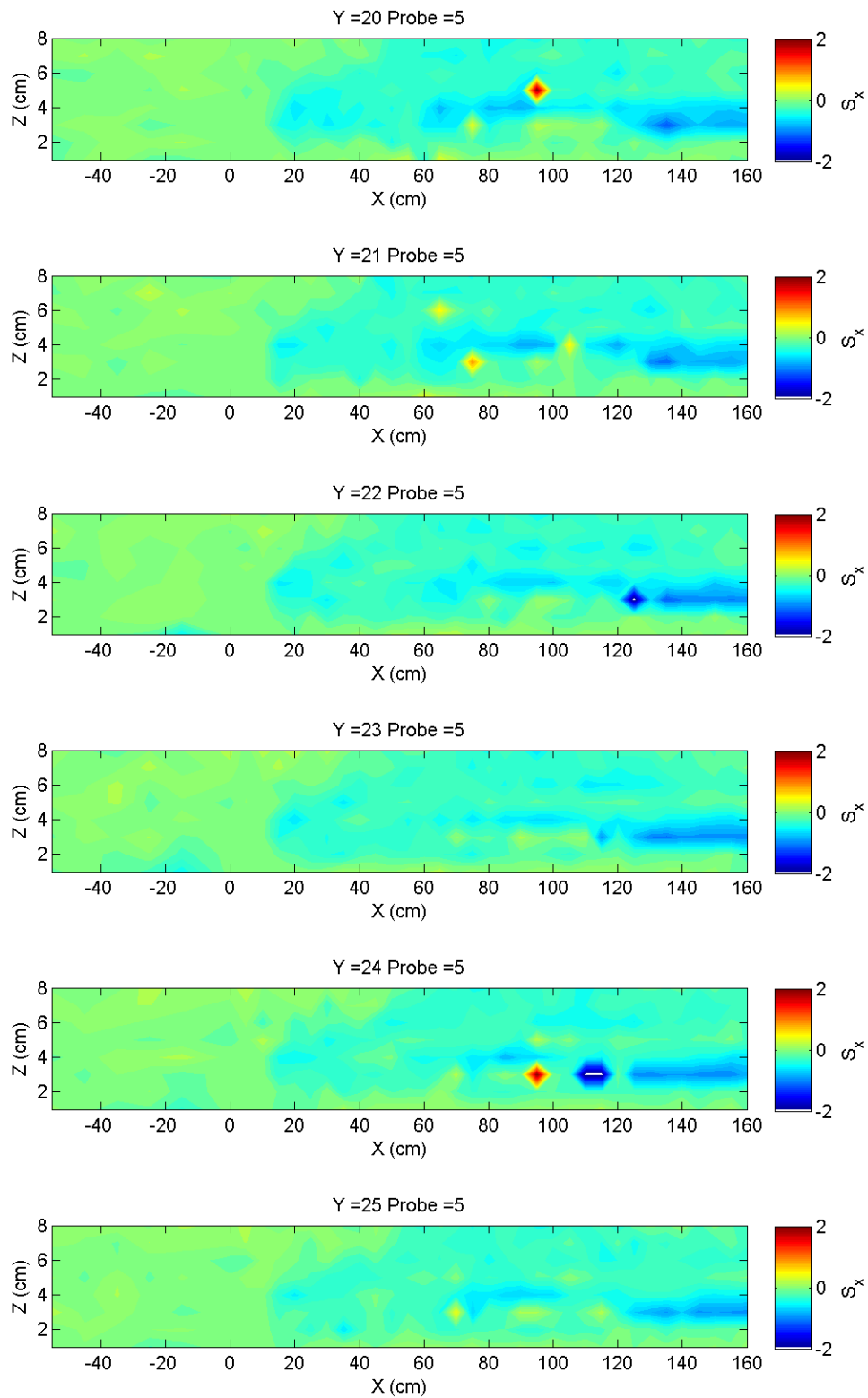


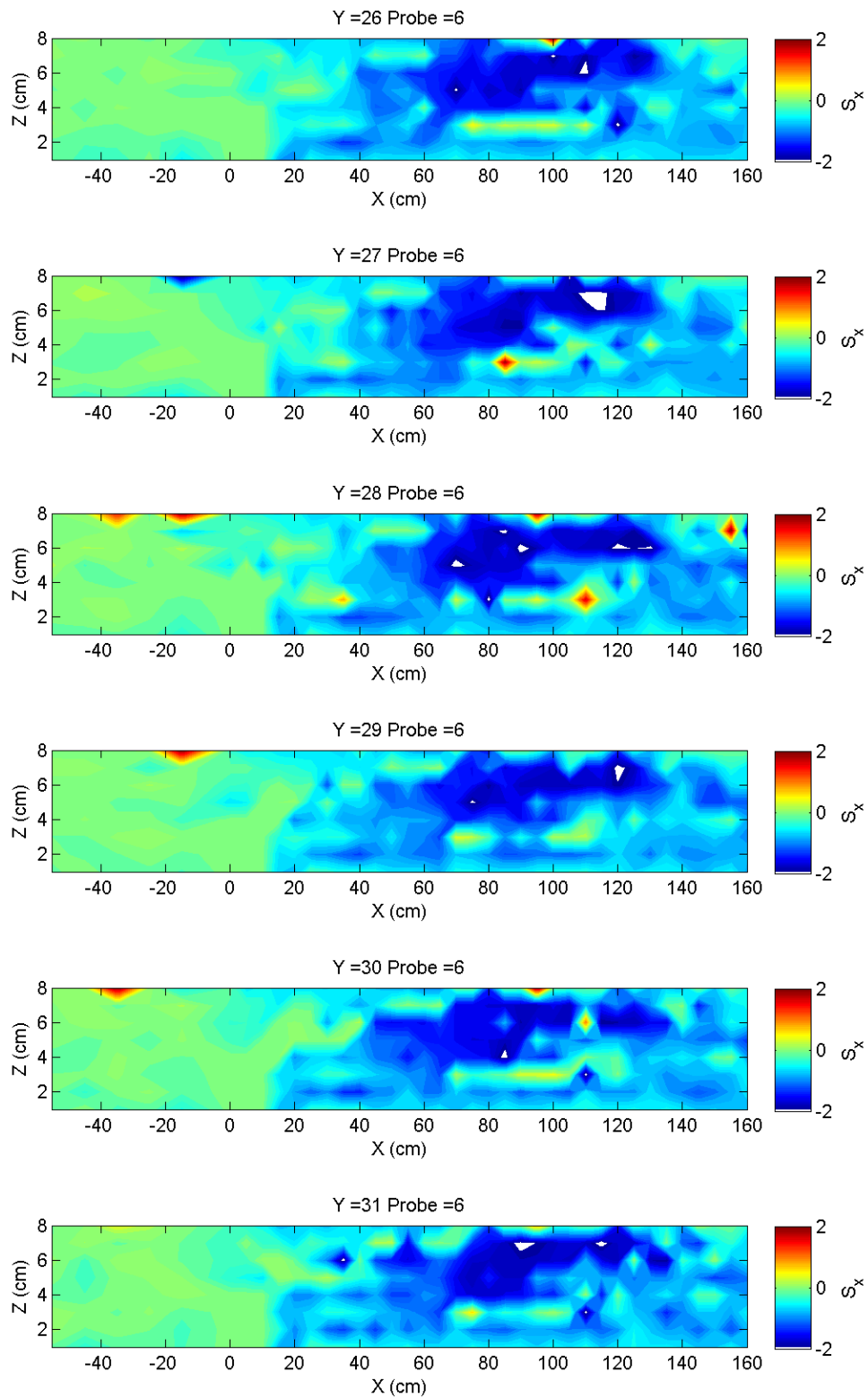


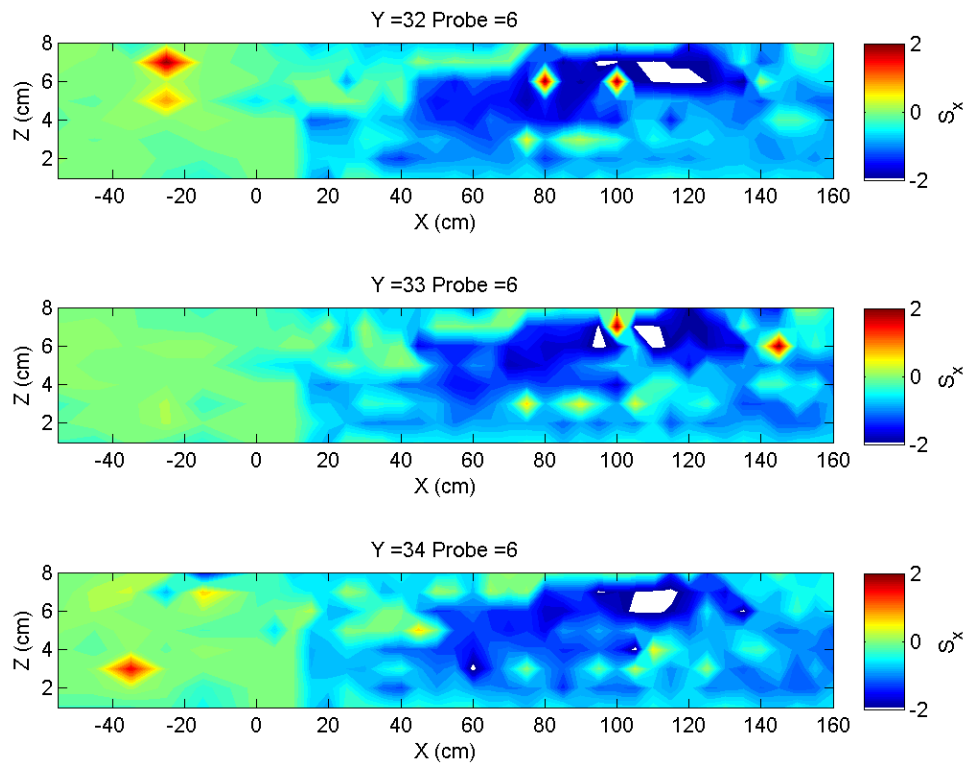




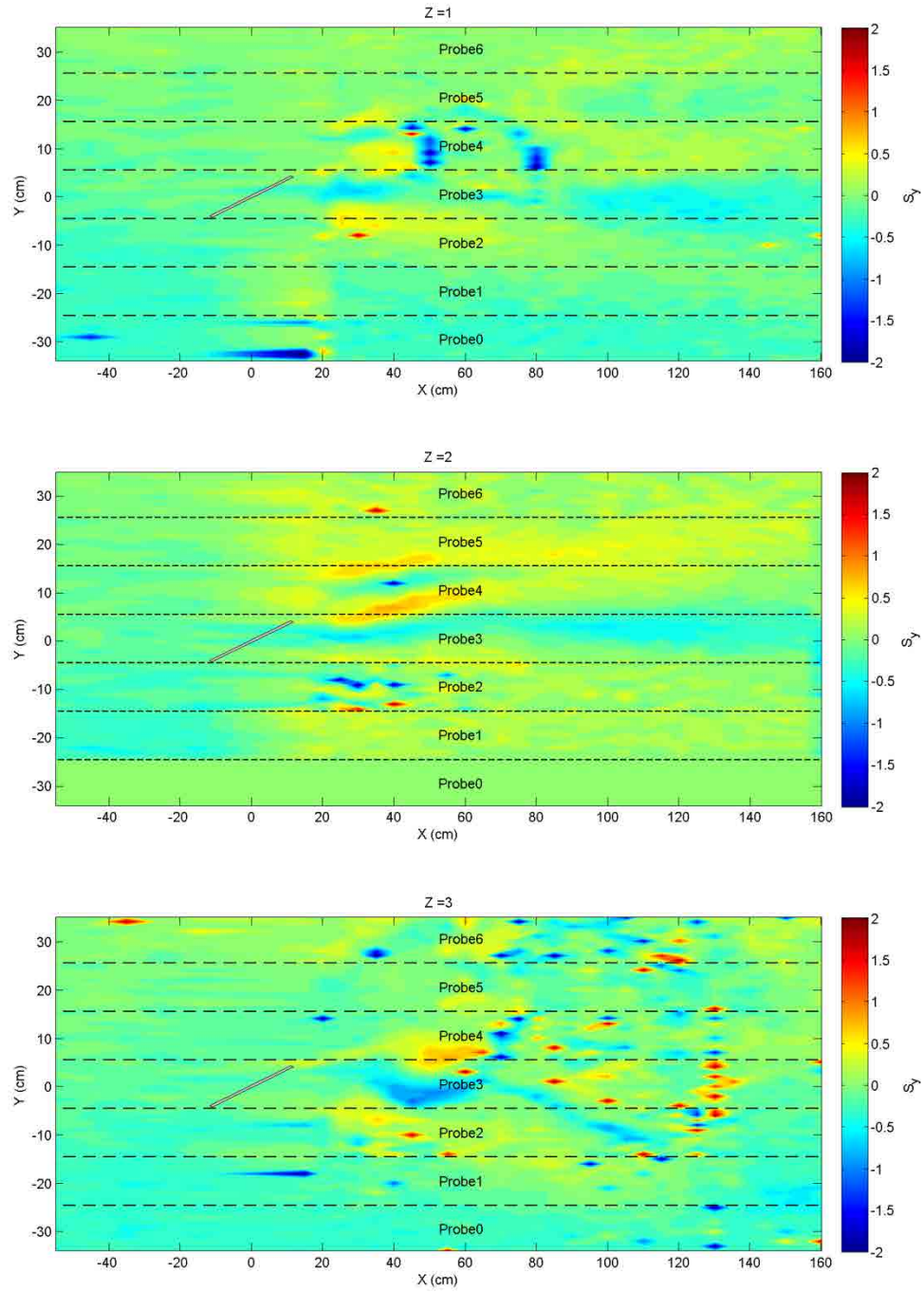


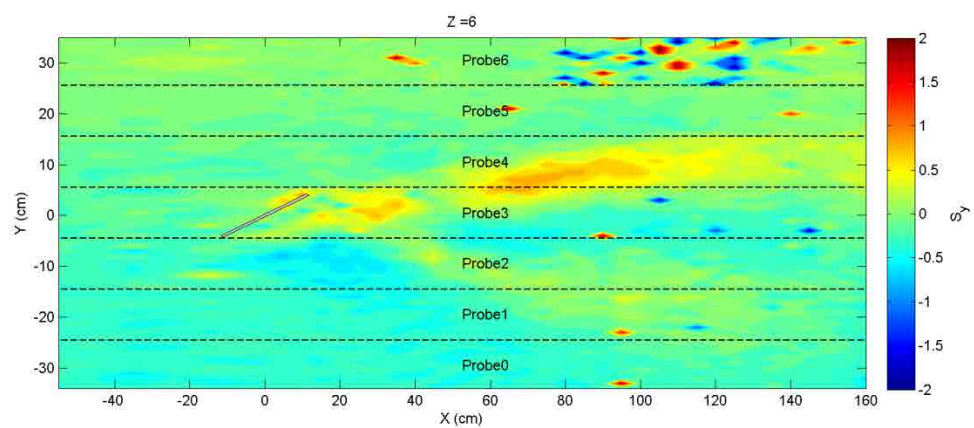
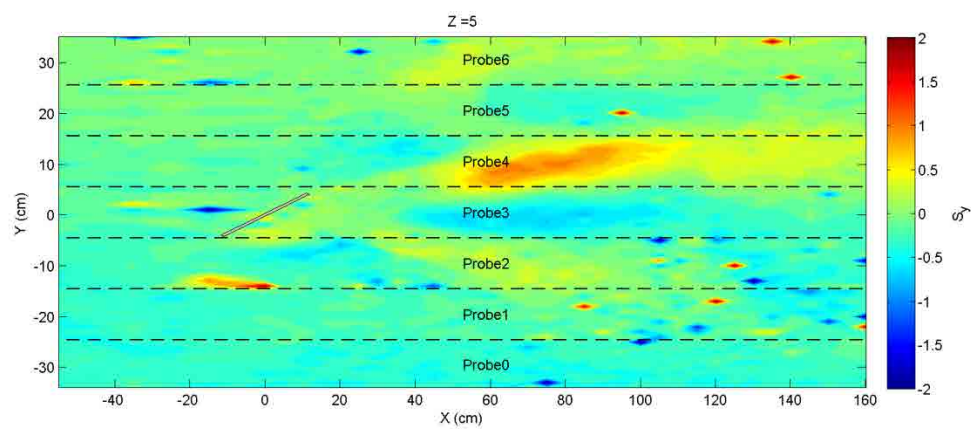
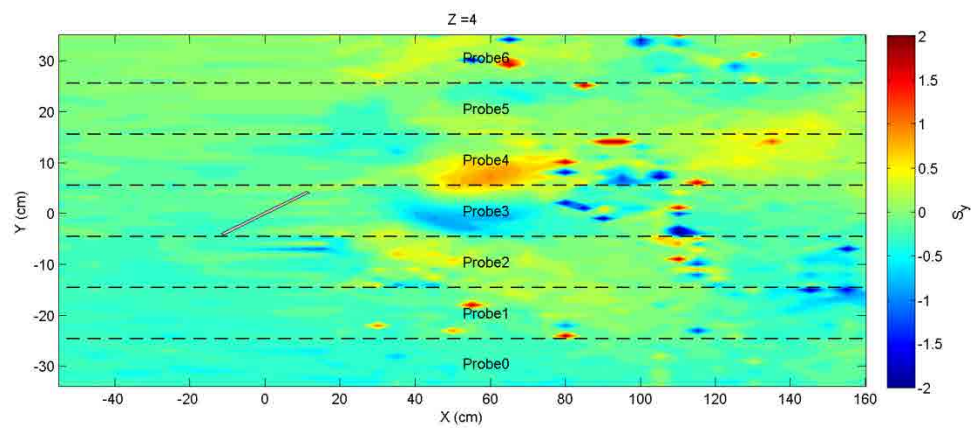


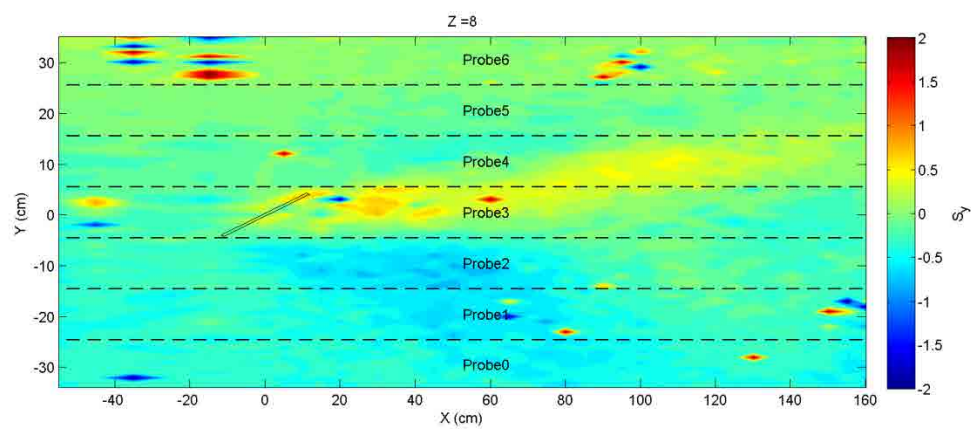
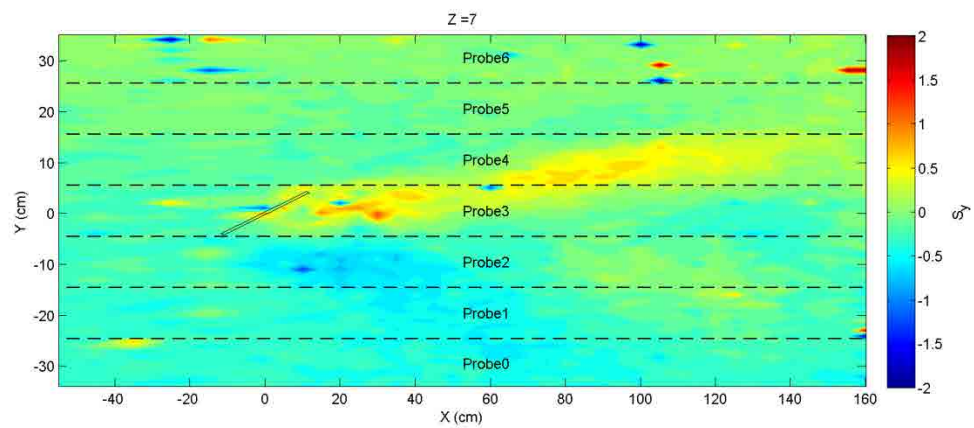




## Skewness Factor $S_y$ in x and y-Directions

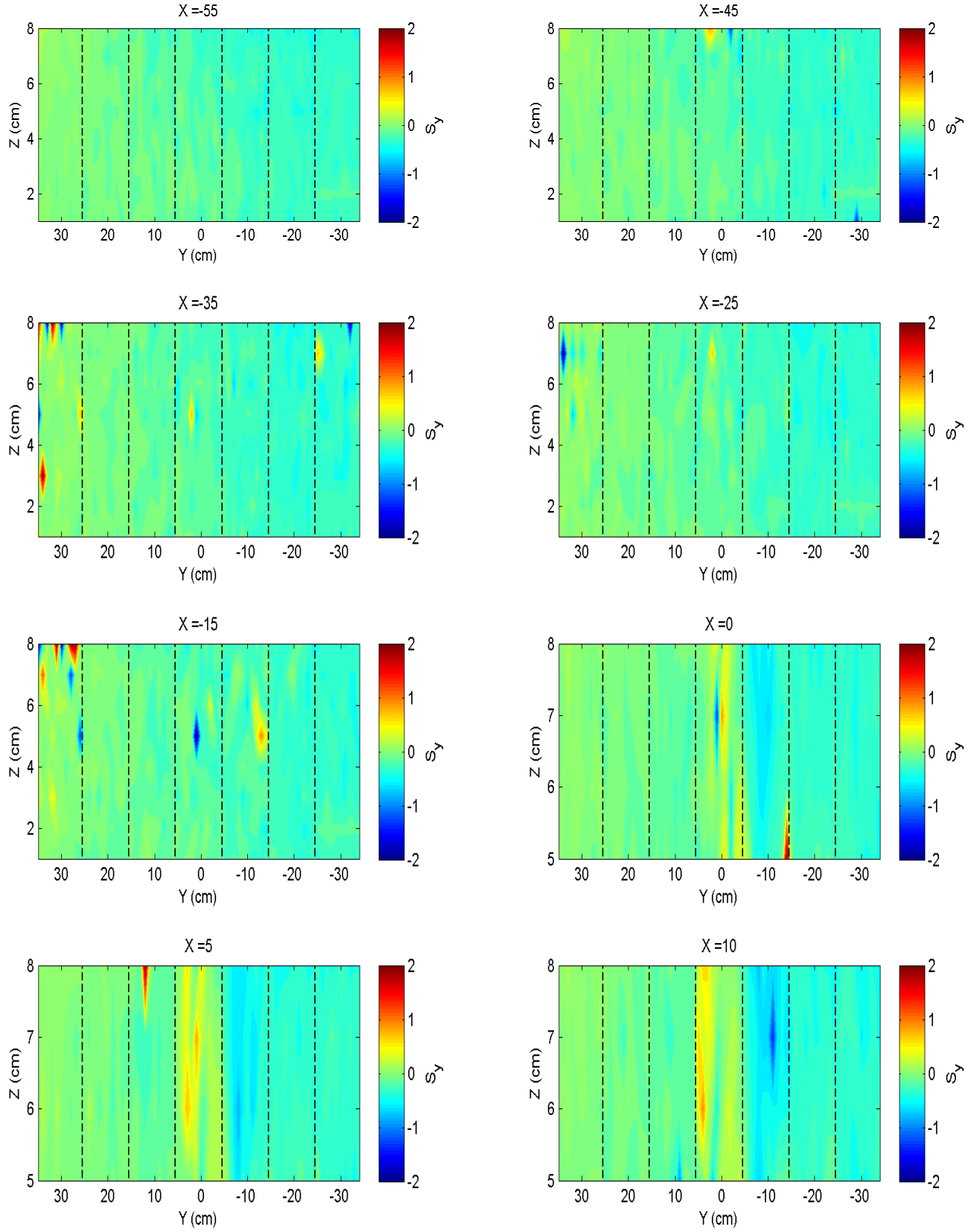


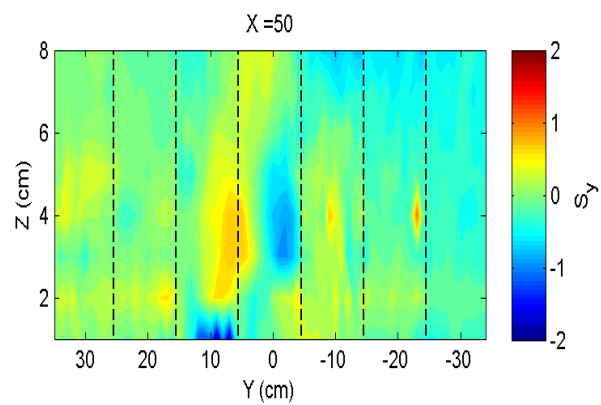
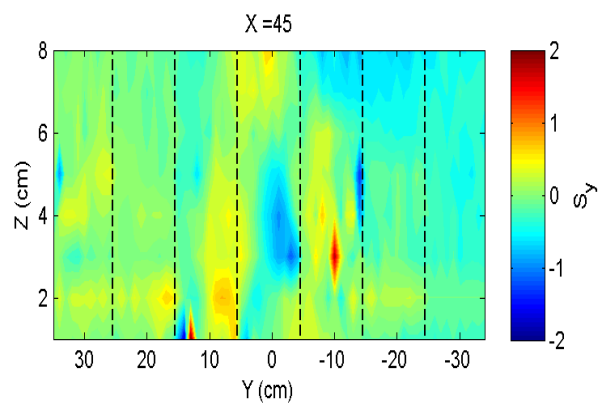
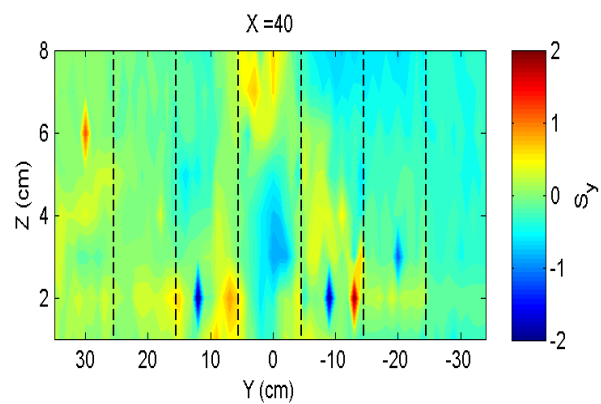
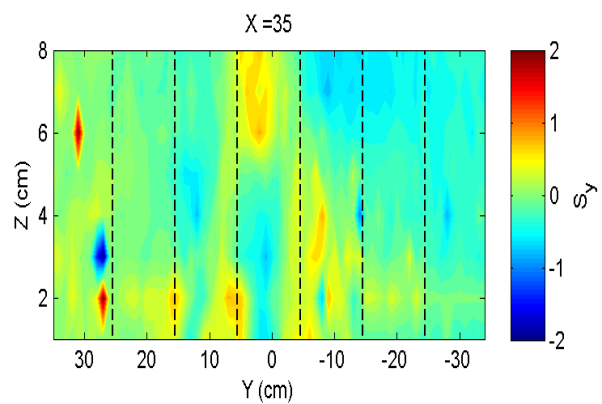
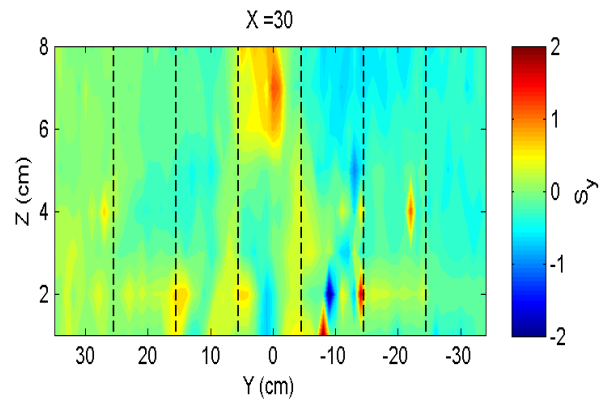
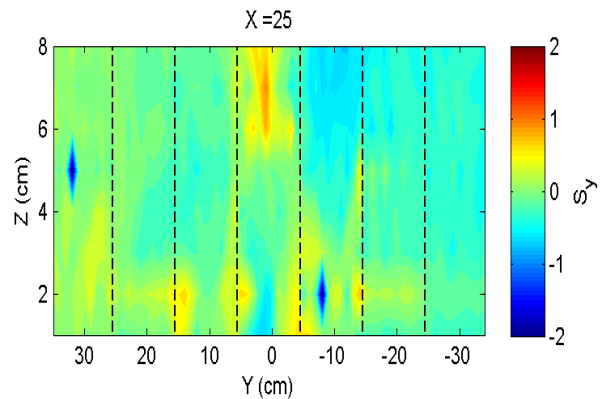
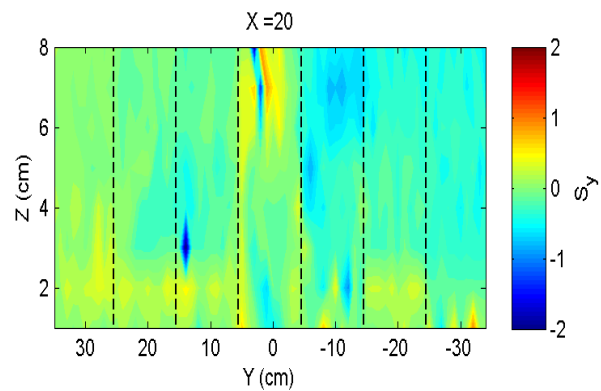
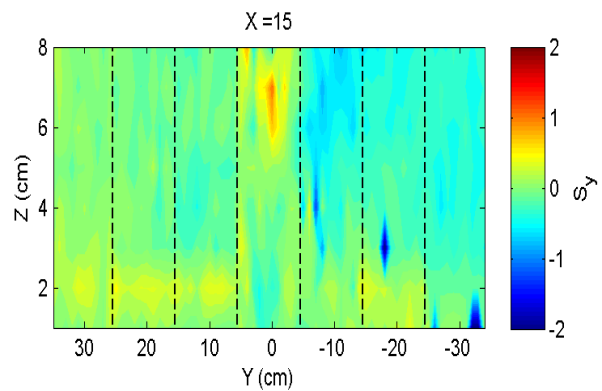




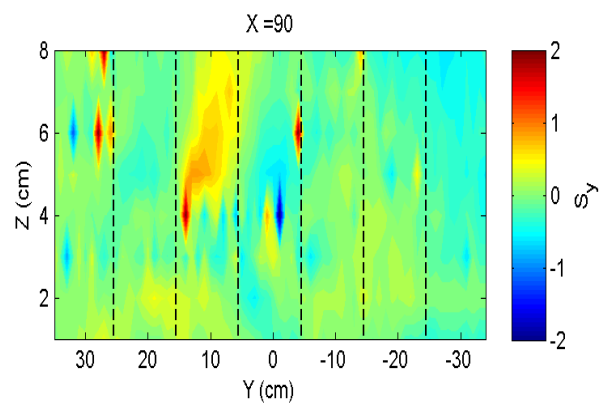
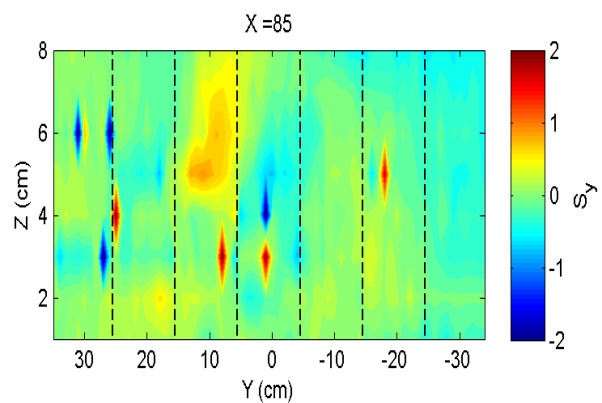
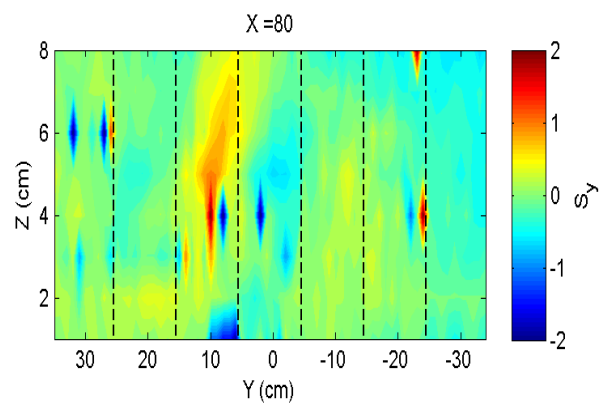
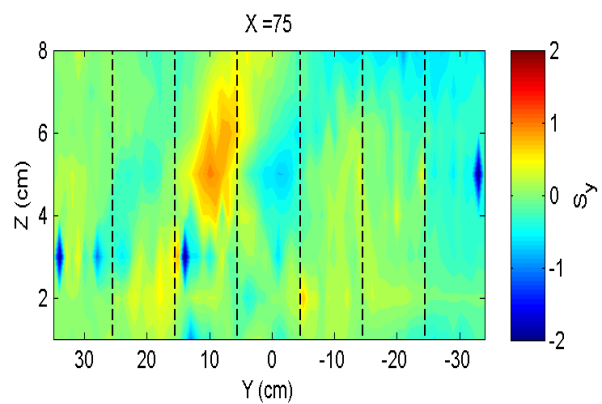
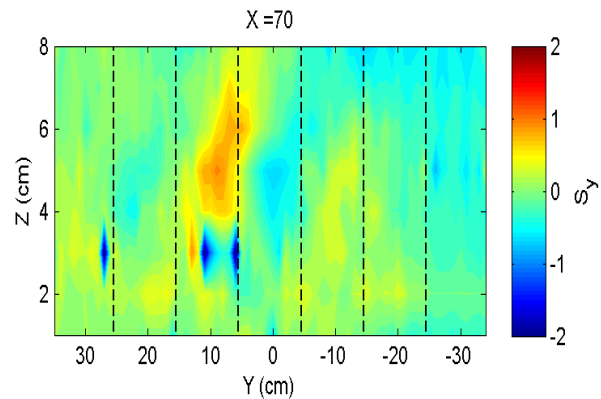
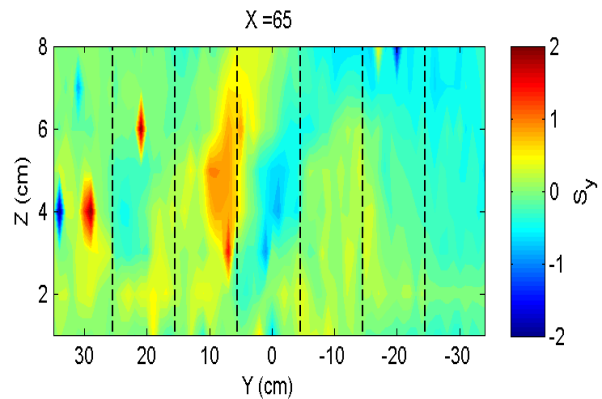
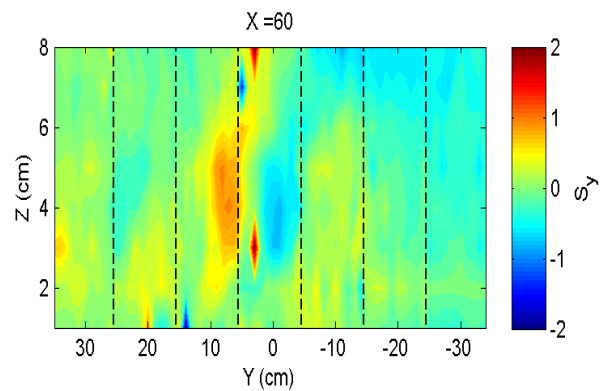
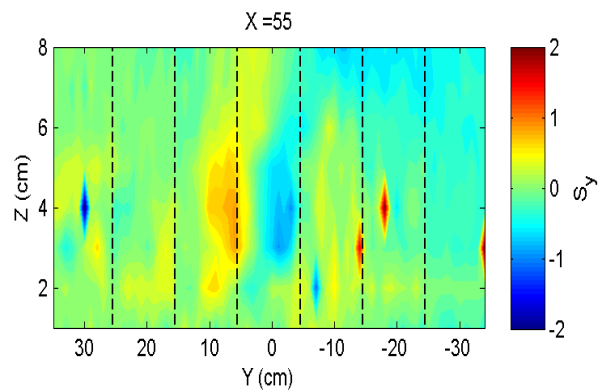


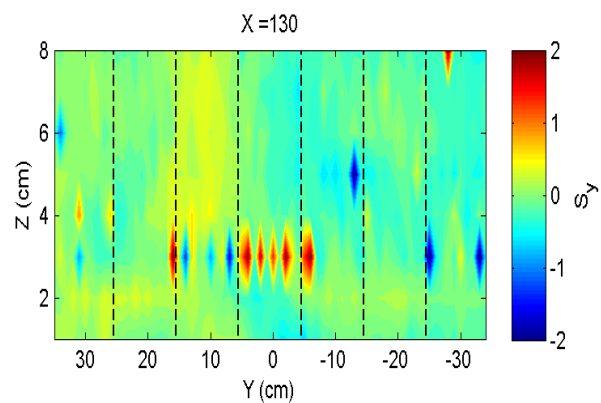
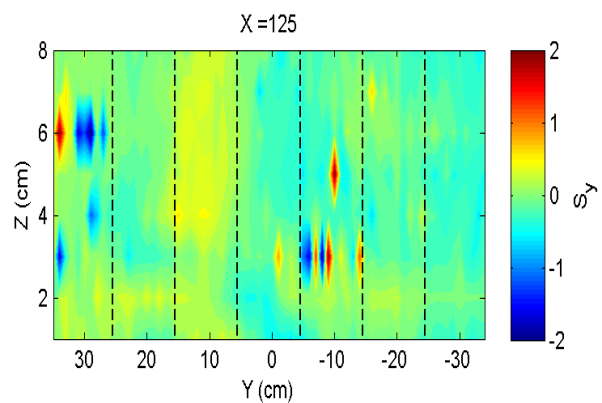
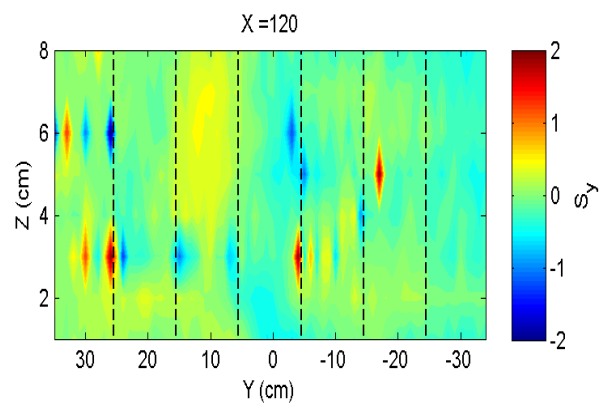
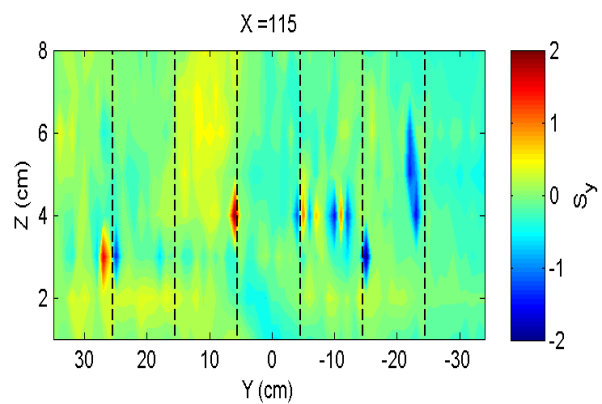
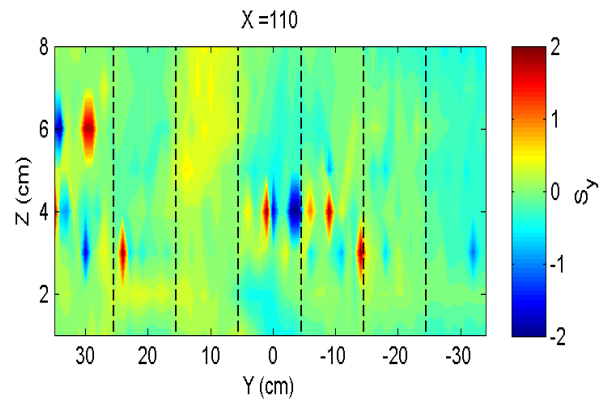
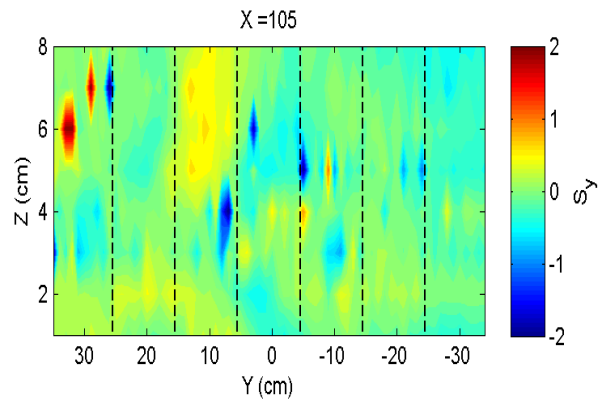
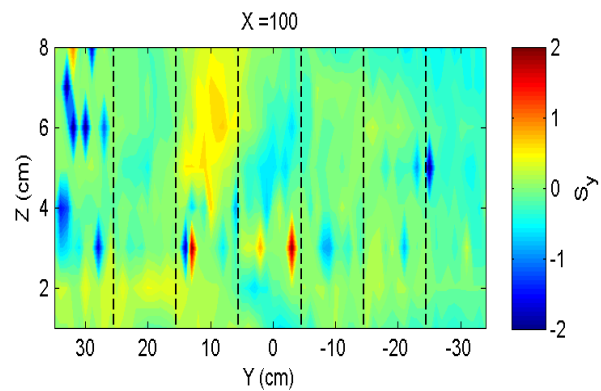
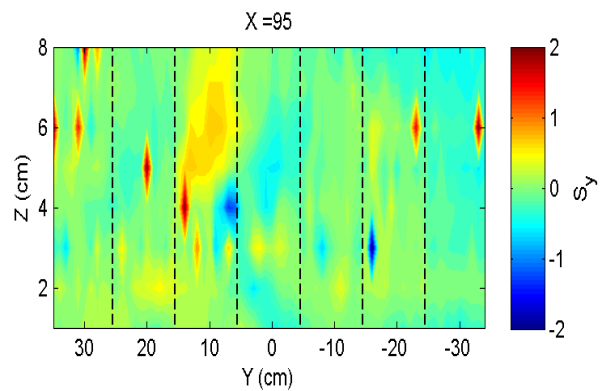
## Skewness Factor $S_y$ in y and z-Directions

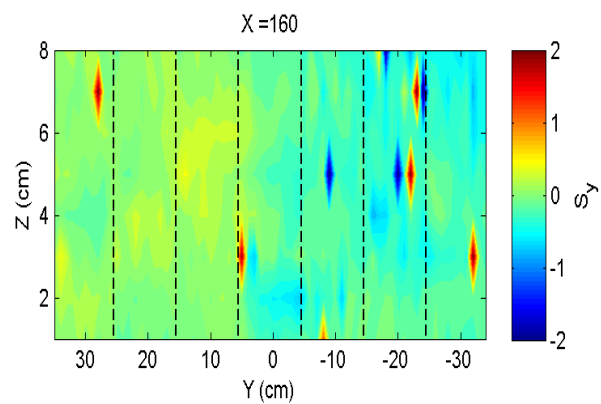
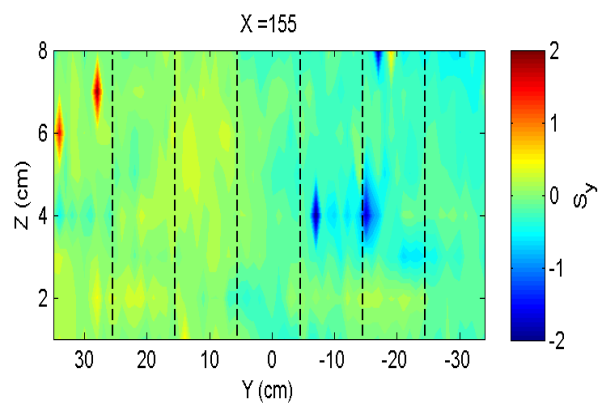
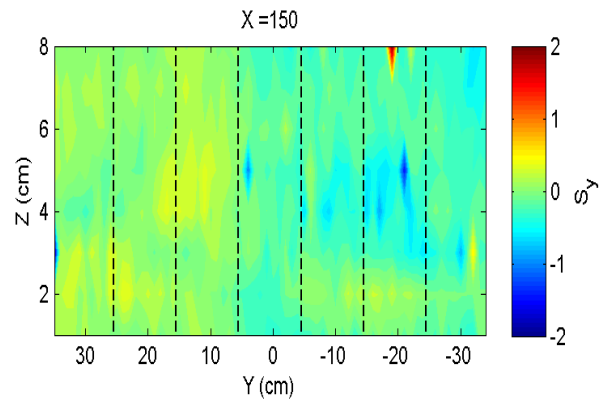
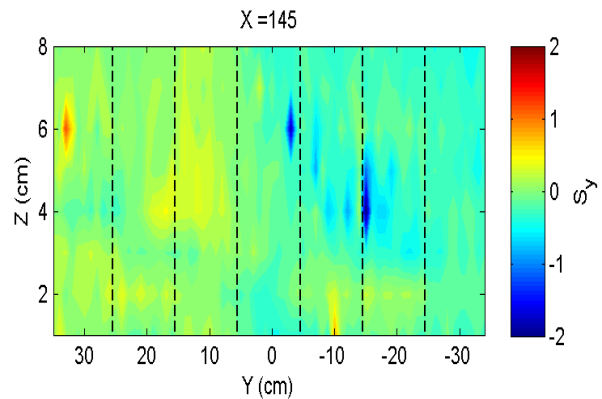
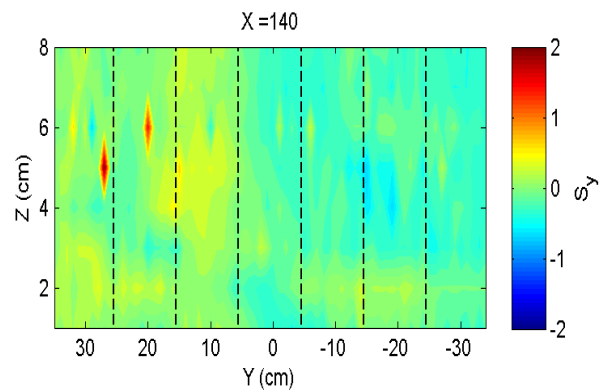
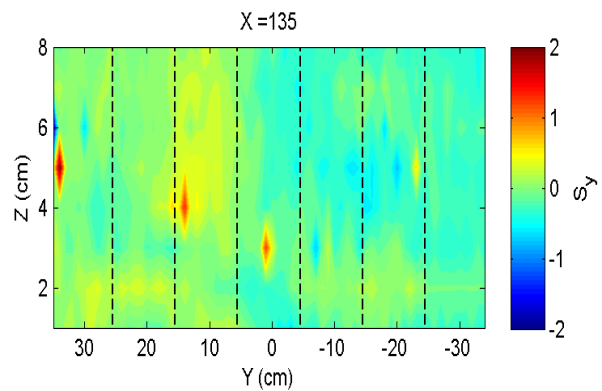




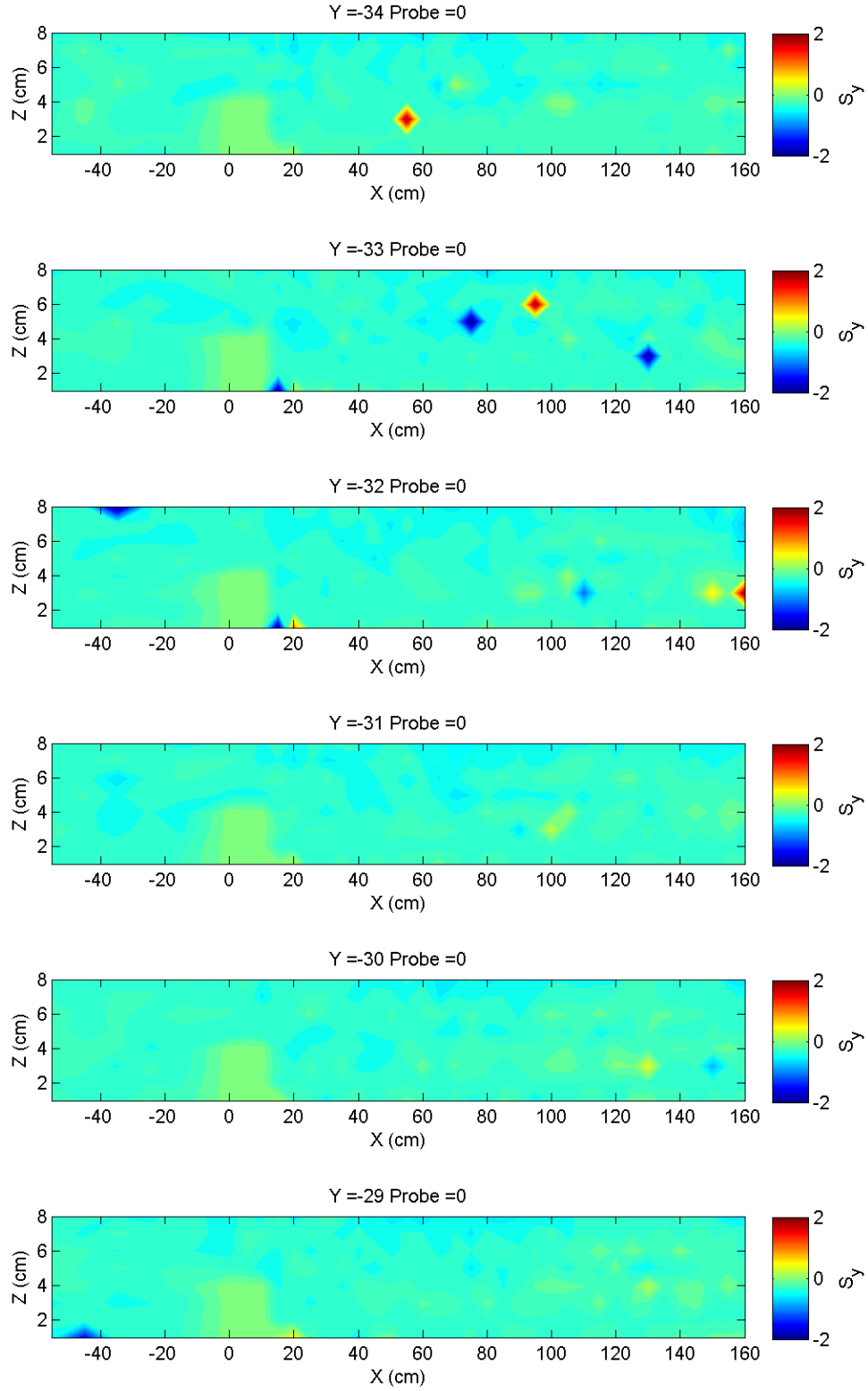


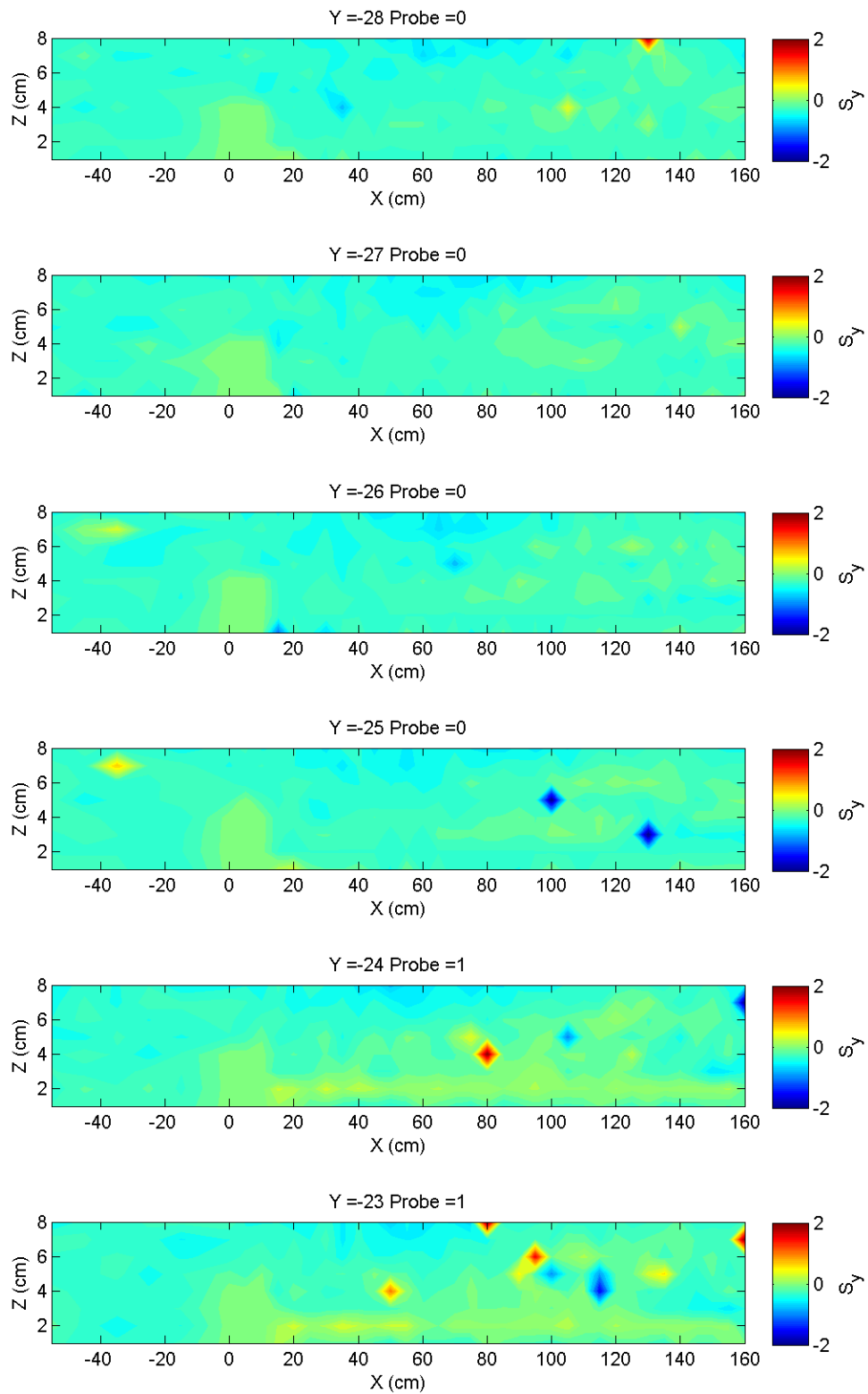


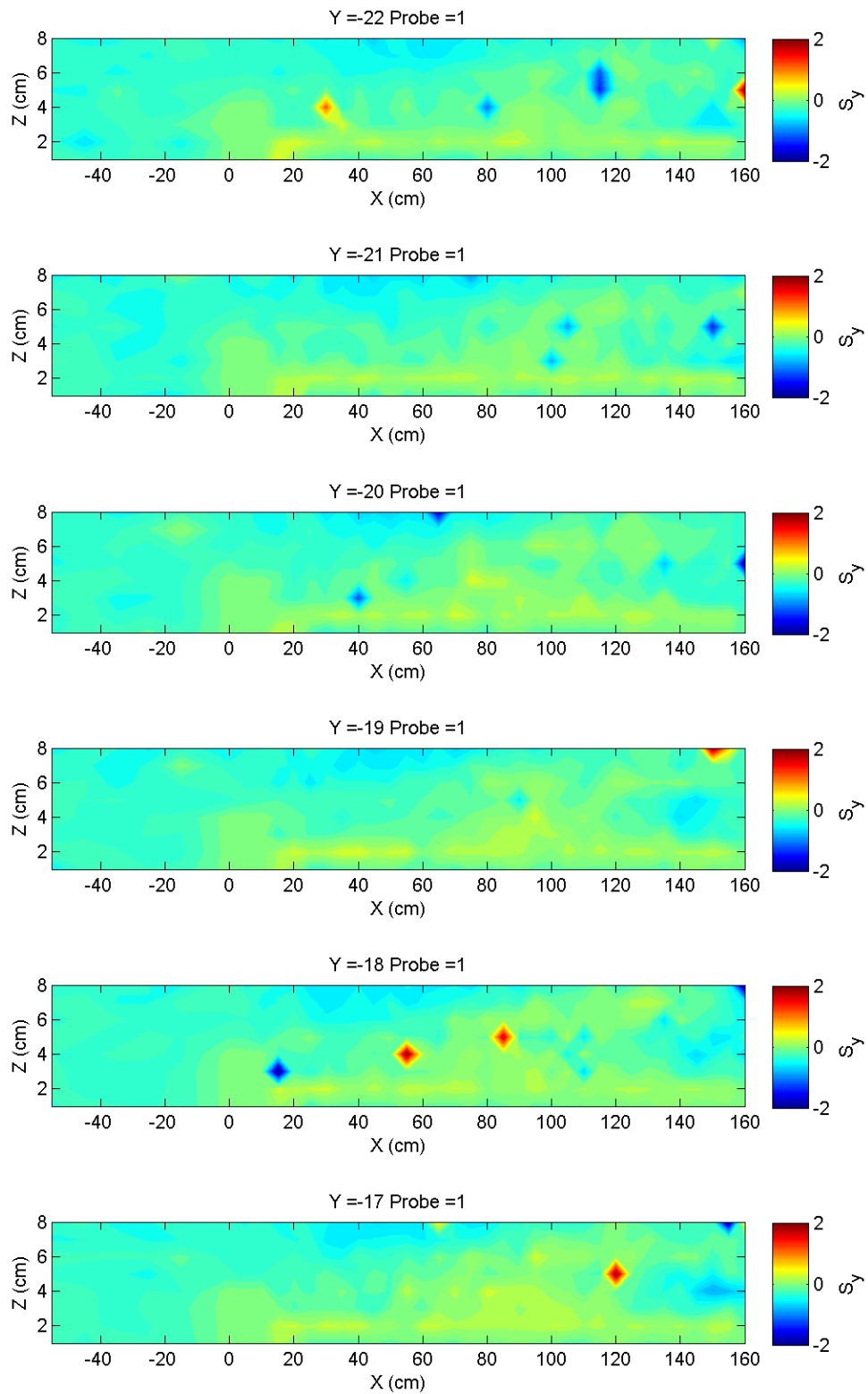


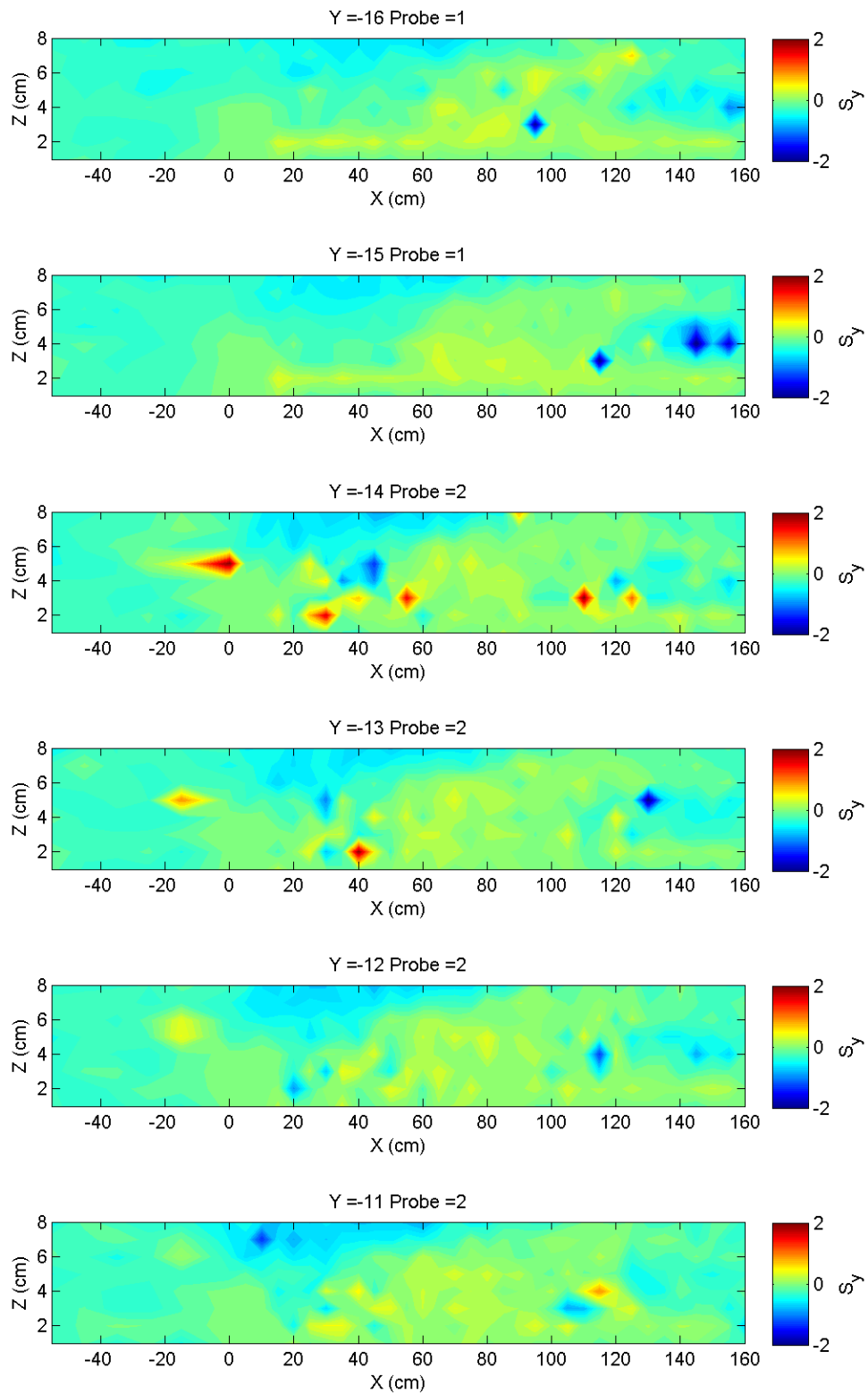


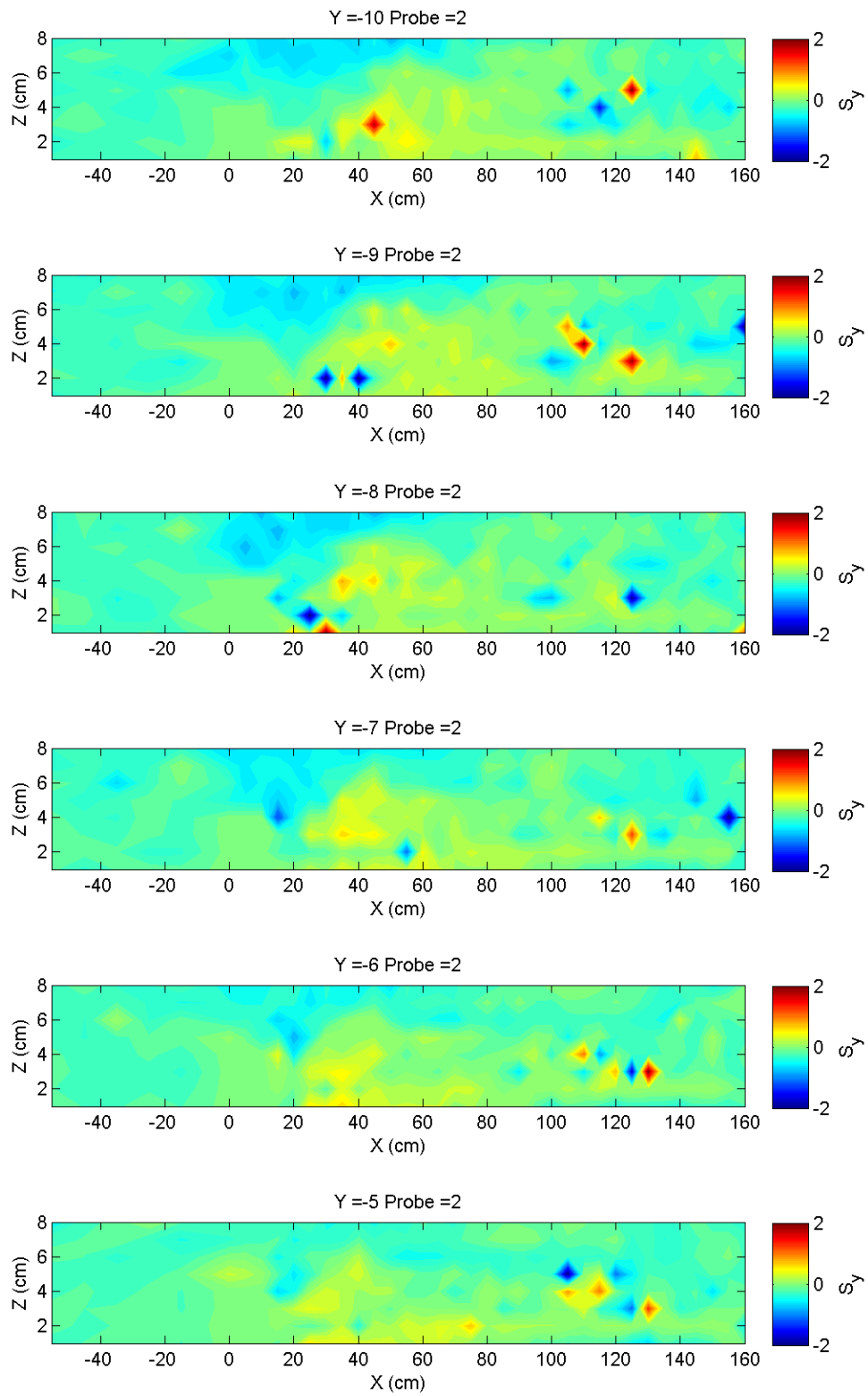
## Skewness Factor $S_y$ in x and z-Directions



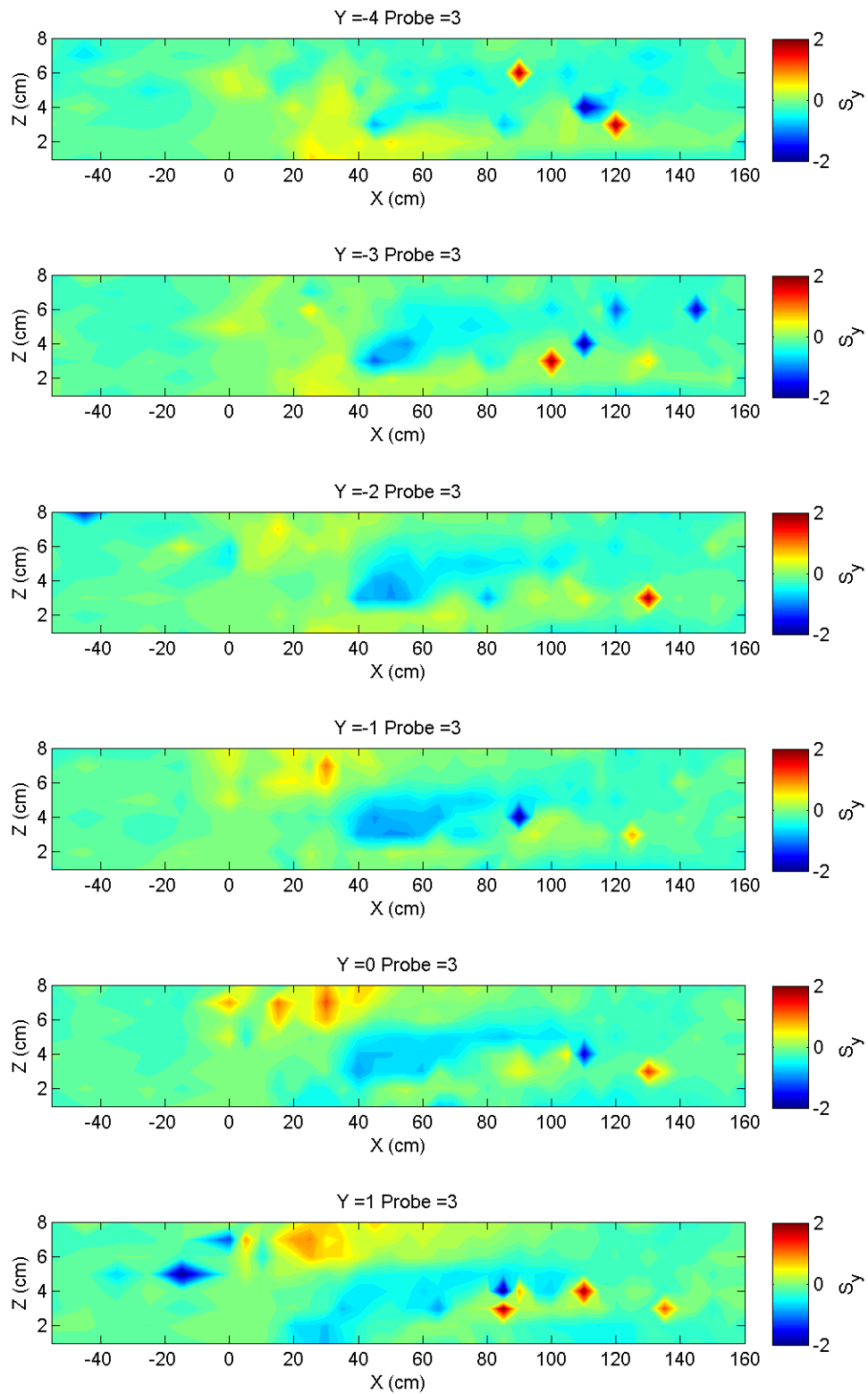


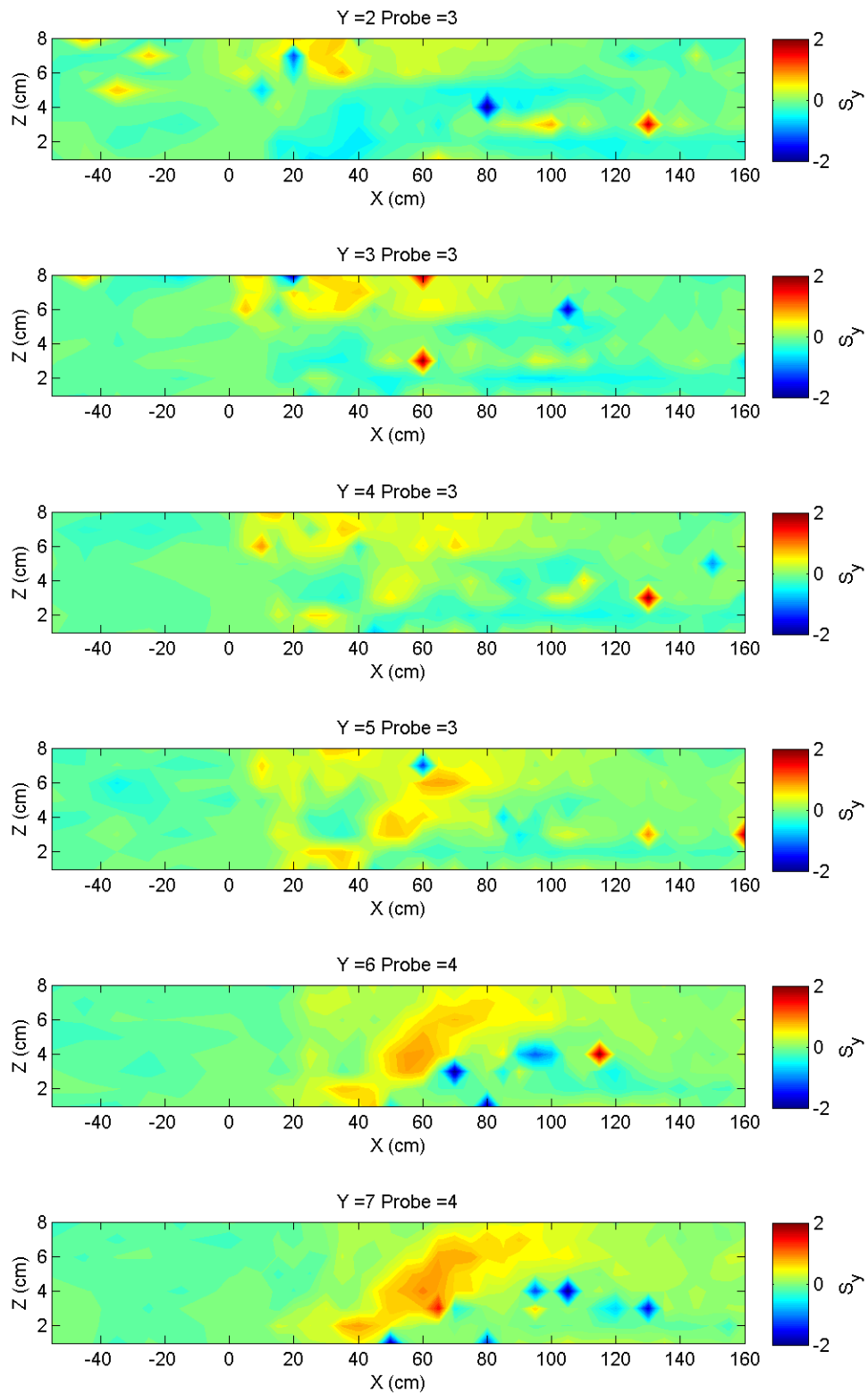


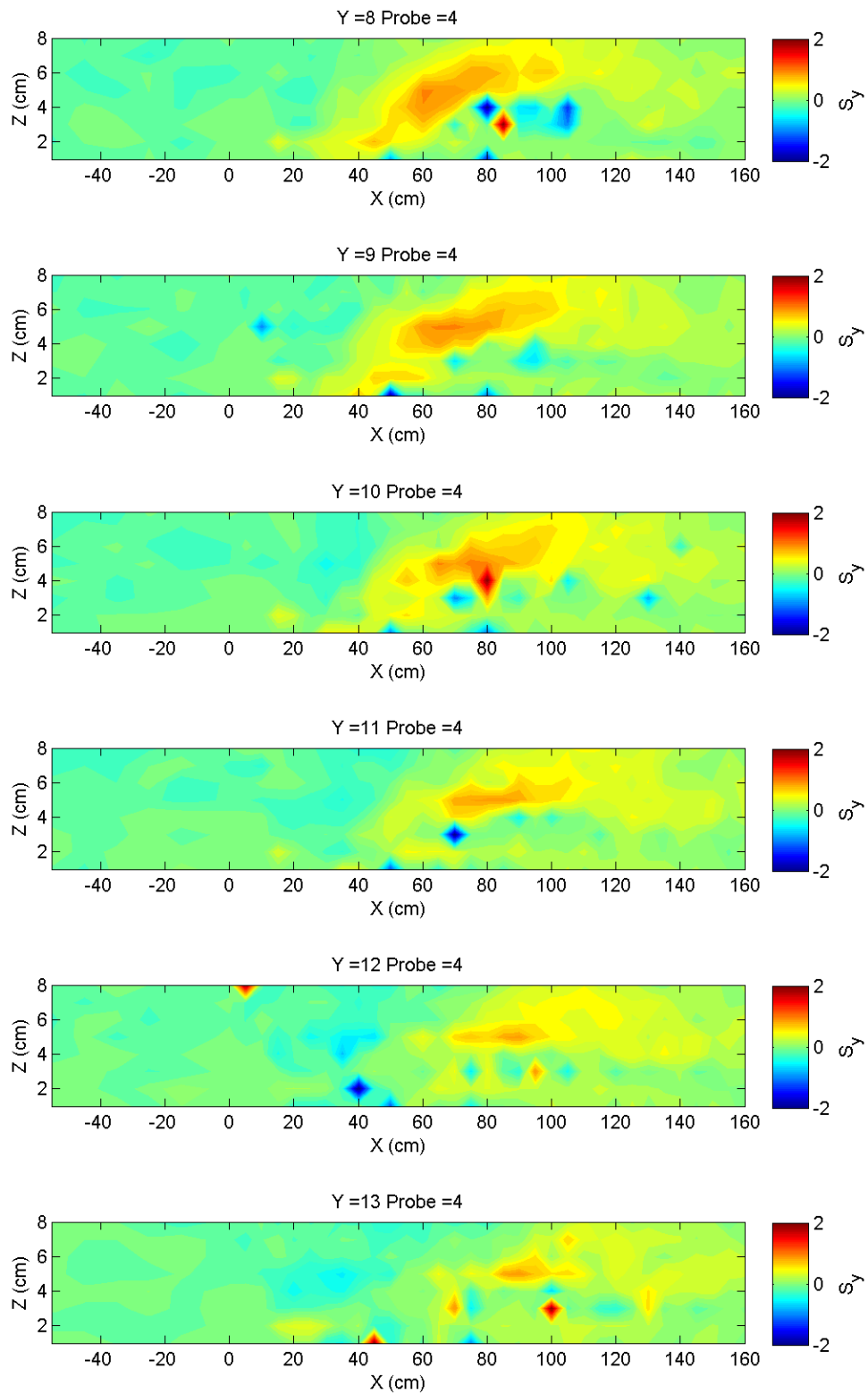


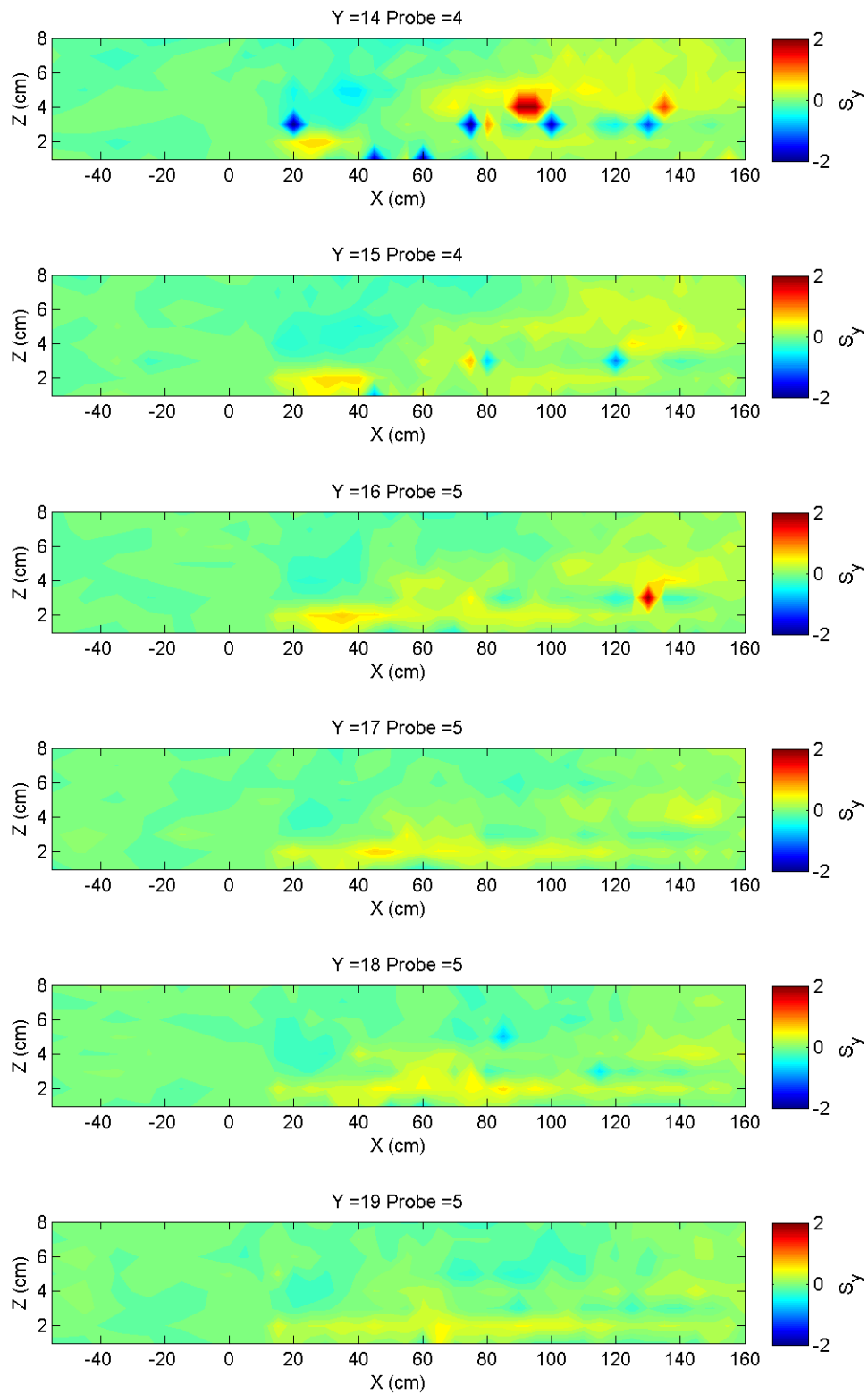


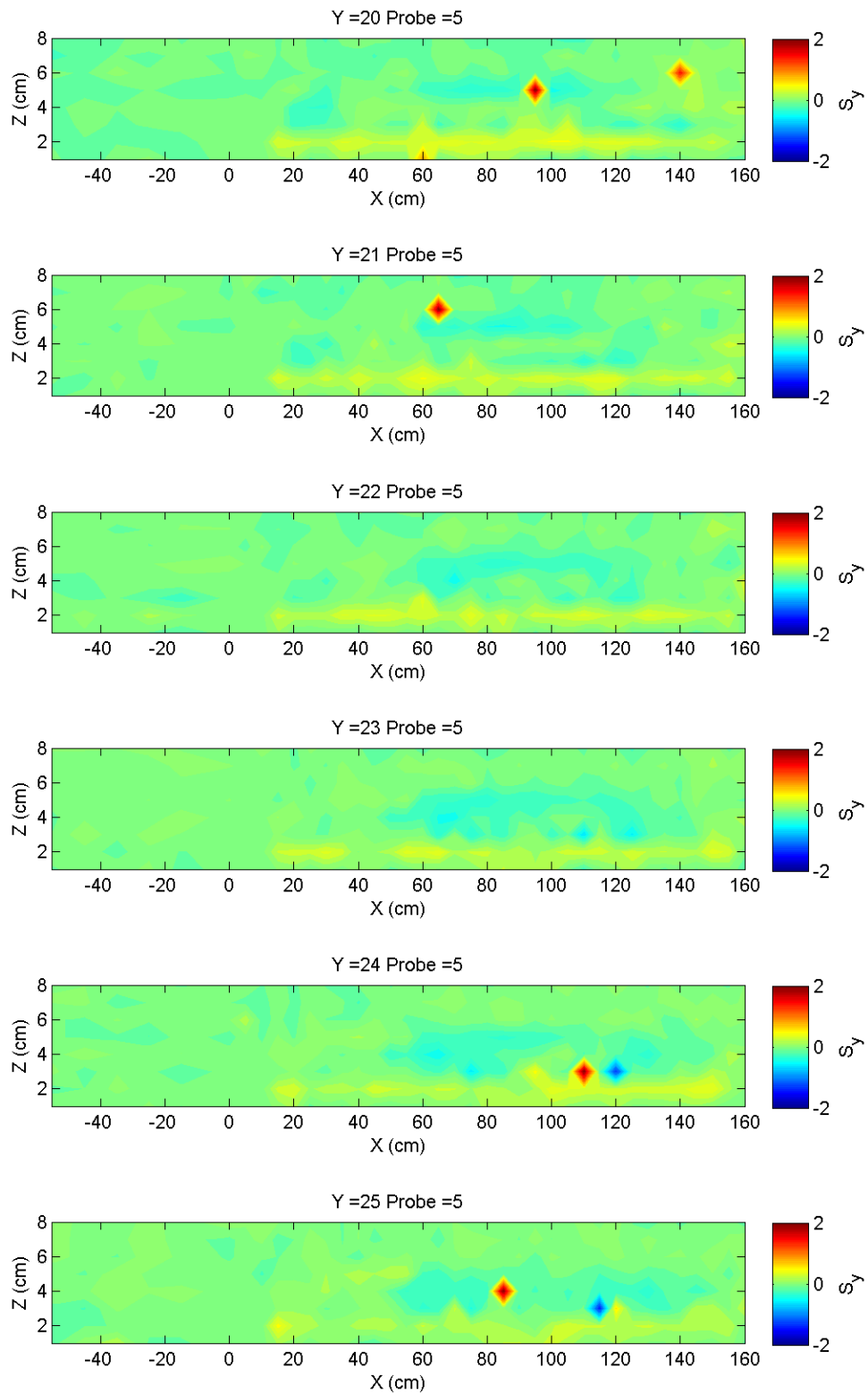


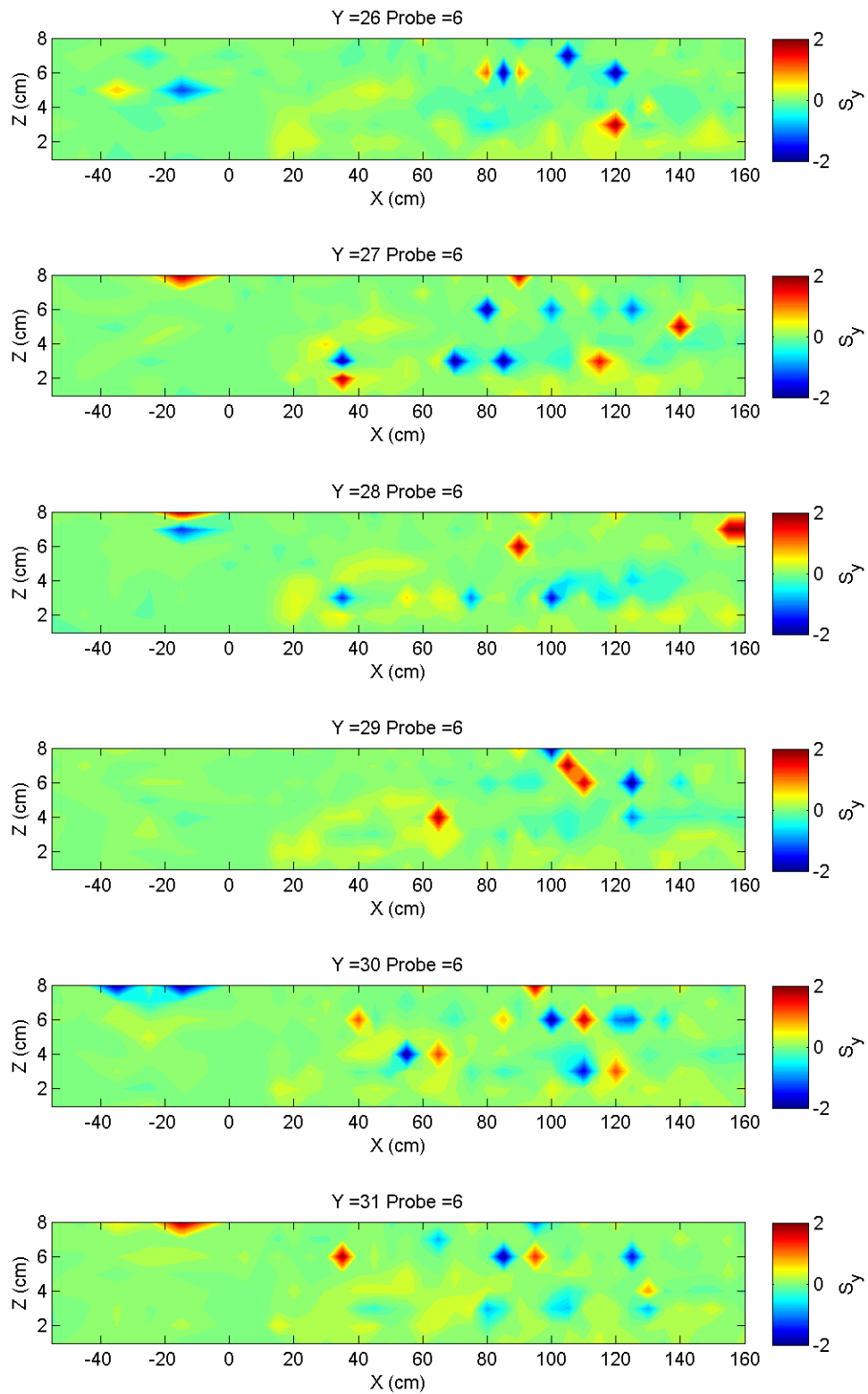


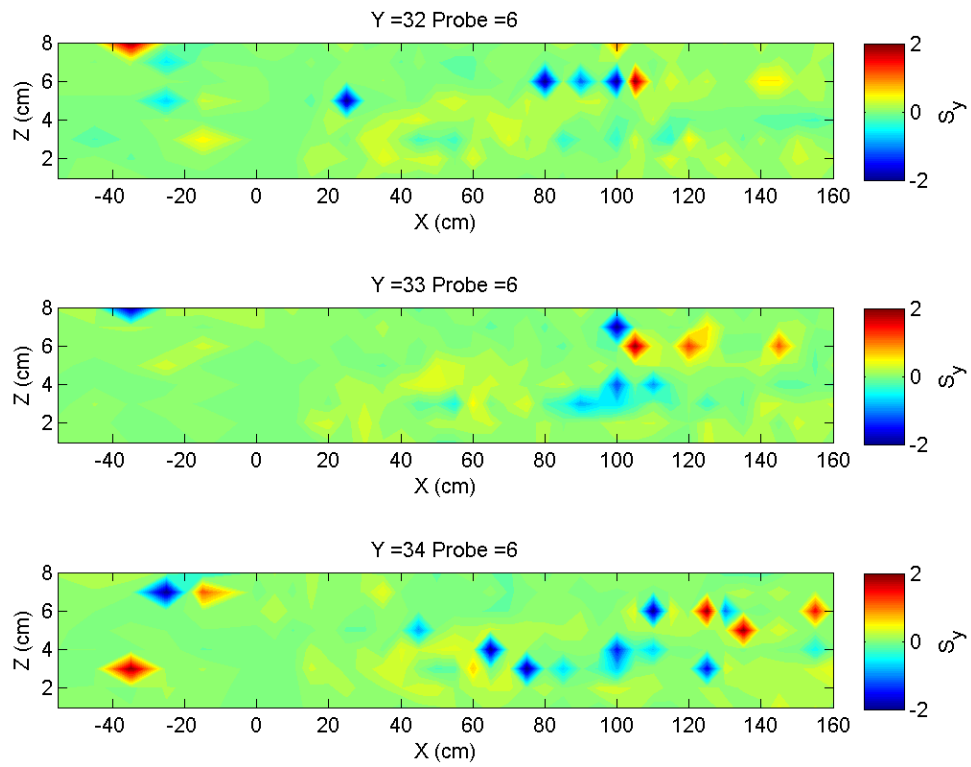




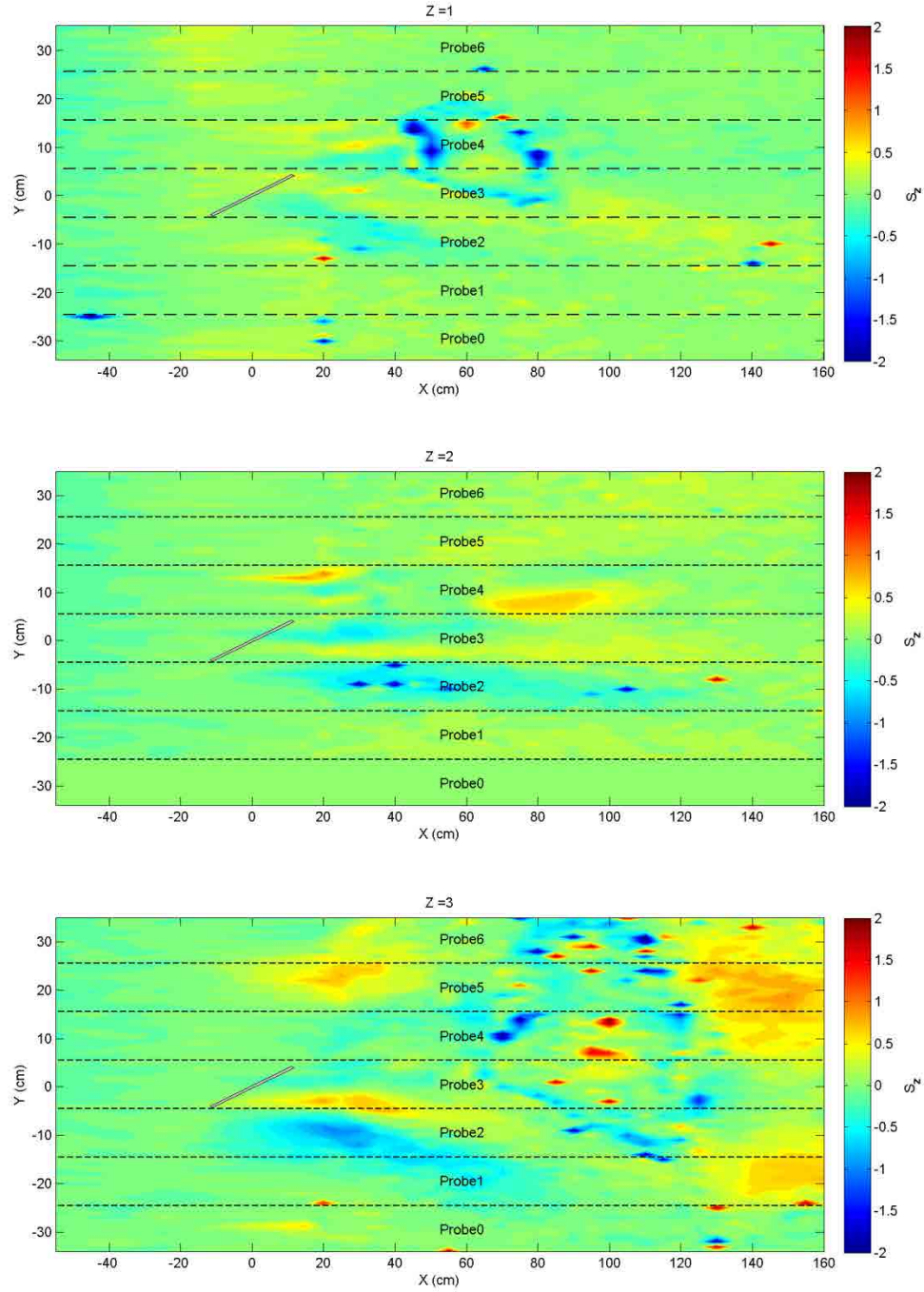




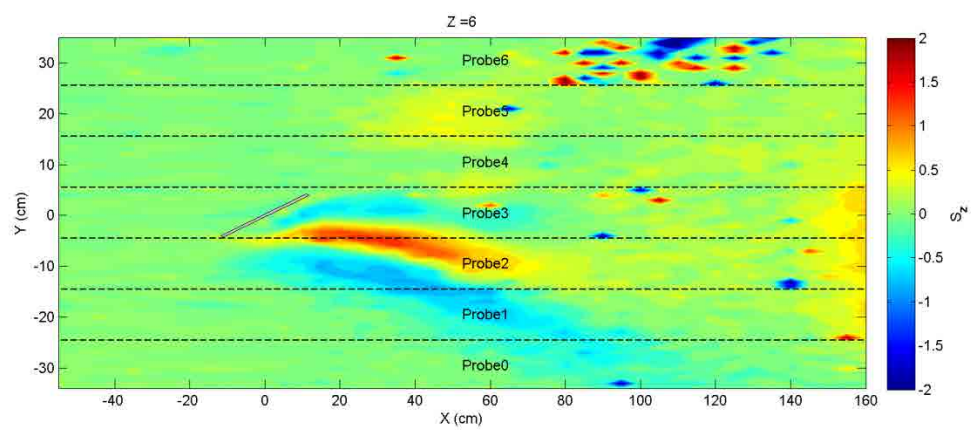
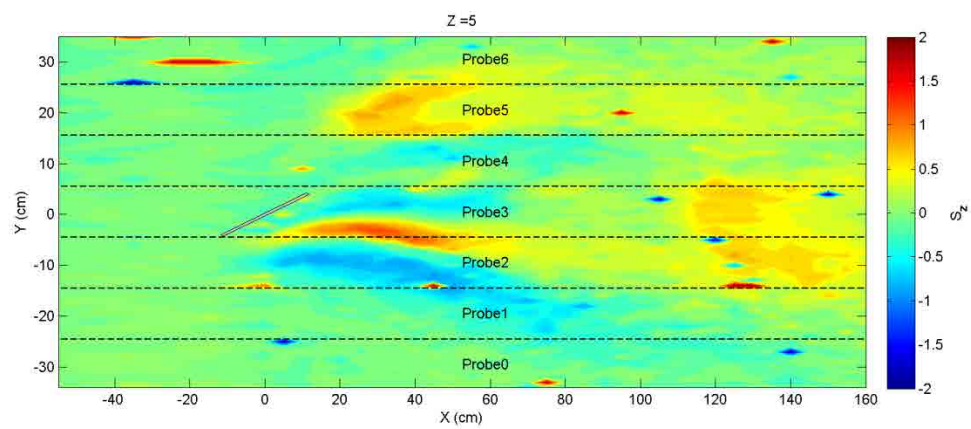
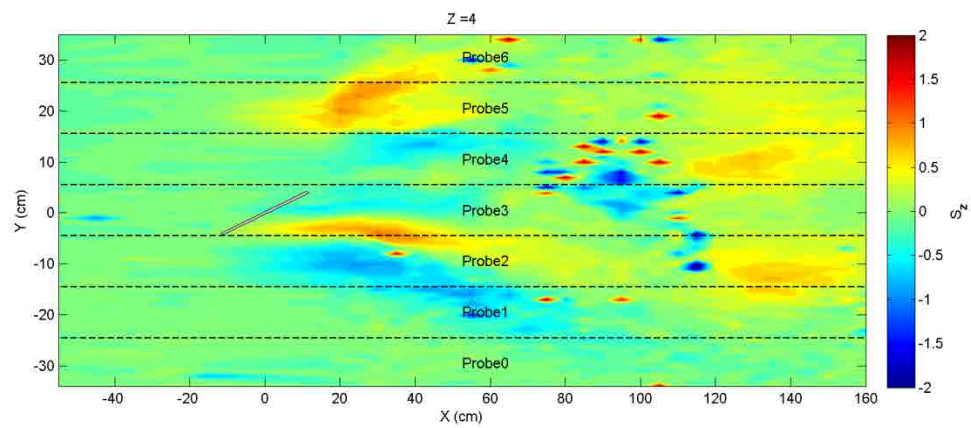


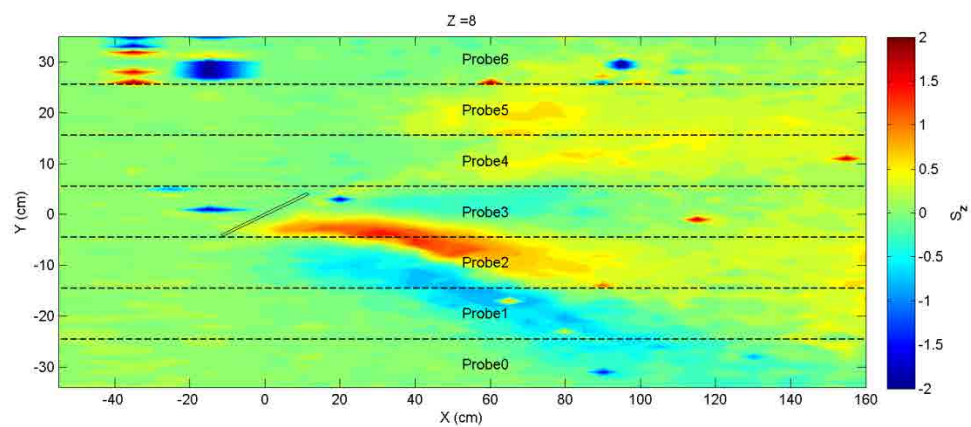
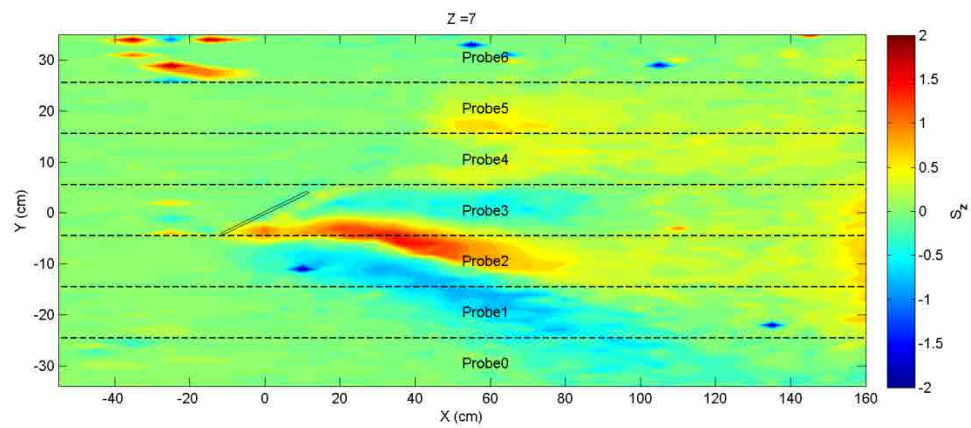


## Skewness Factor $S_z$ in x and y-Directions

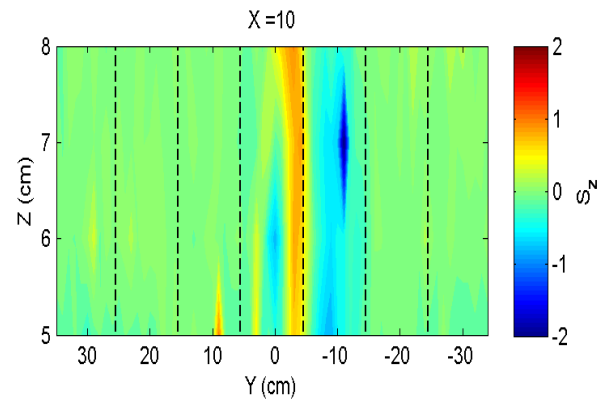
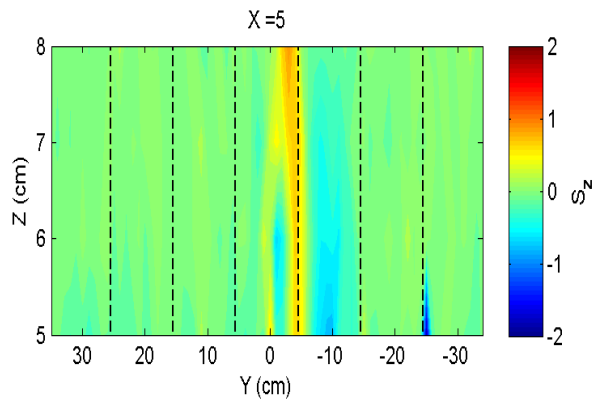
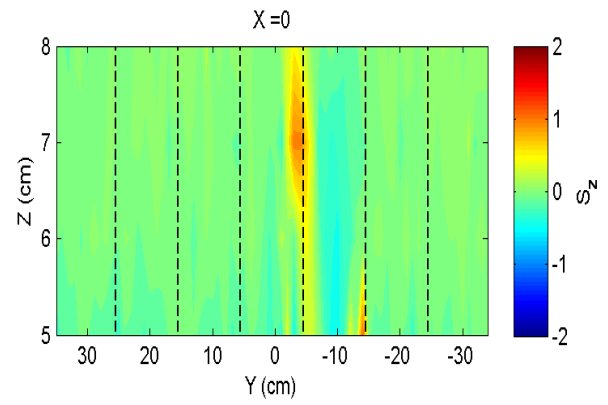
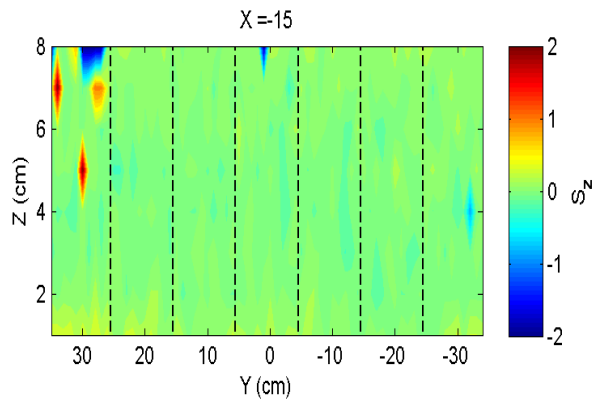
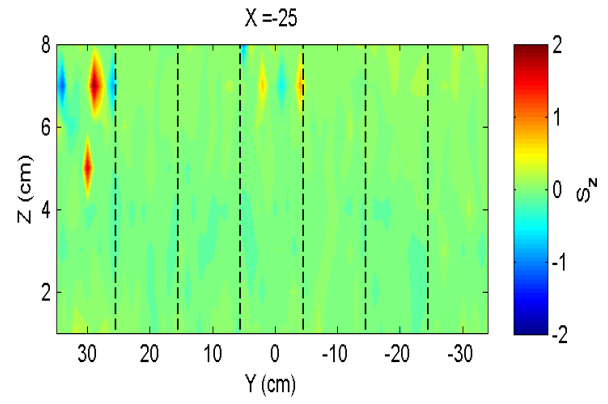
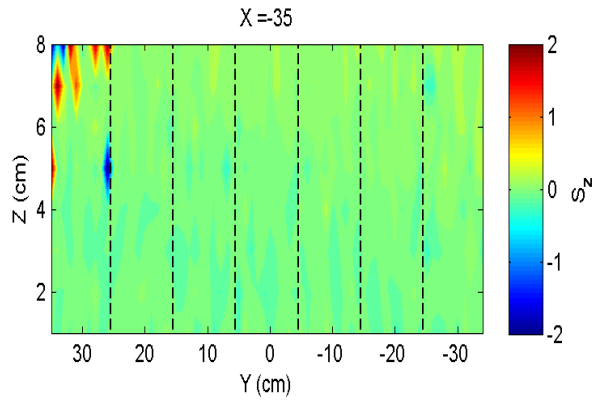
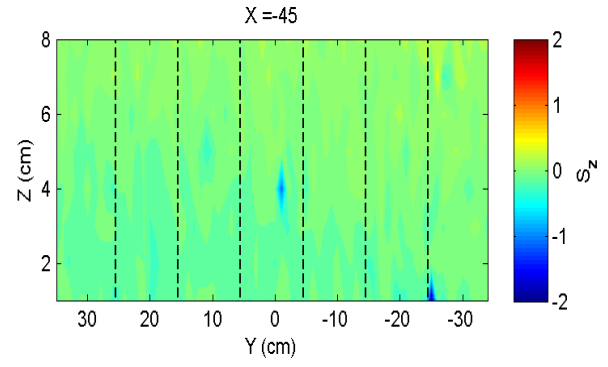
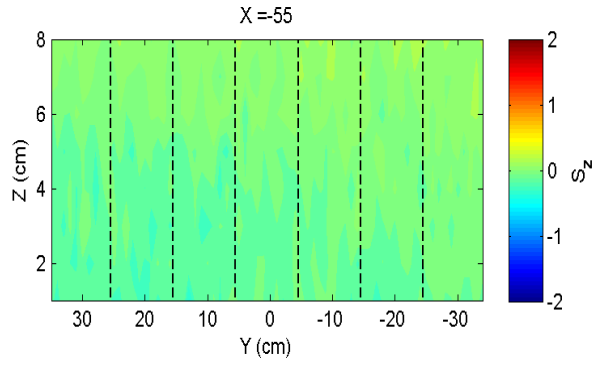


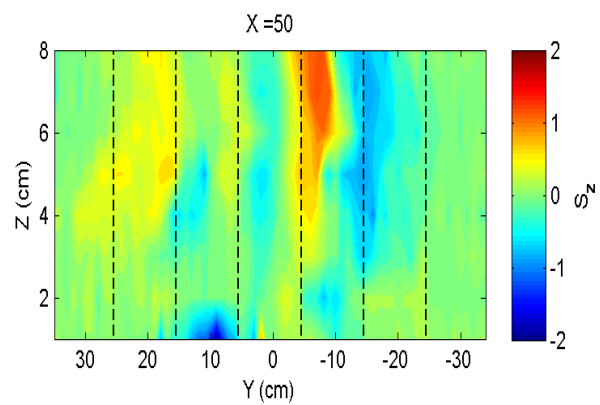
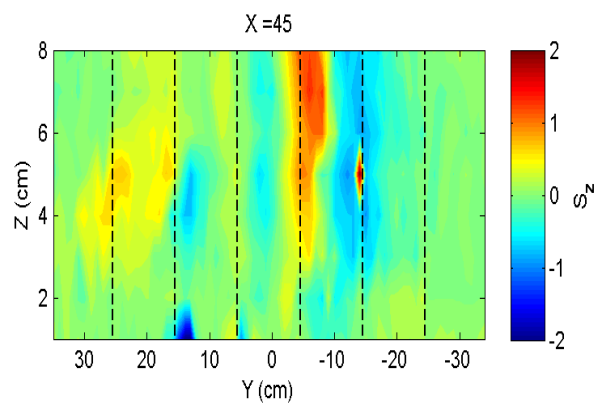
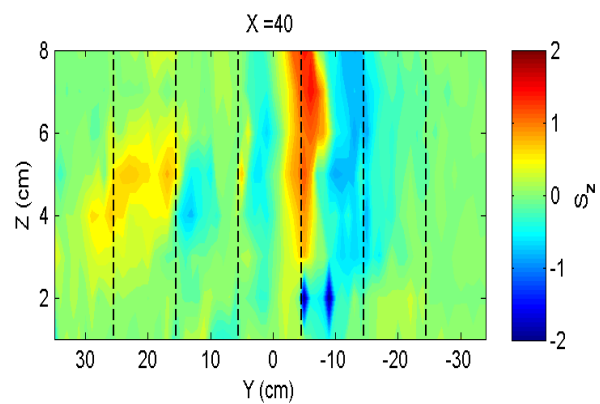
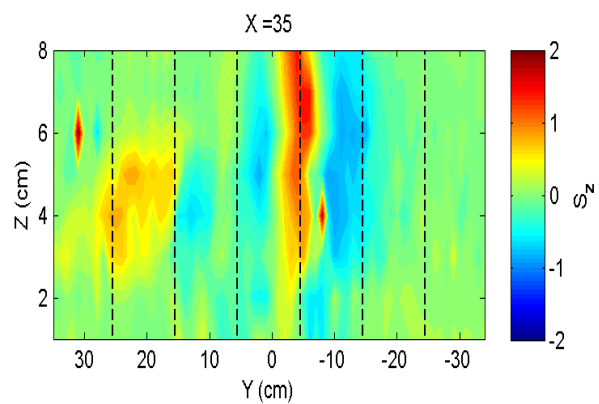
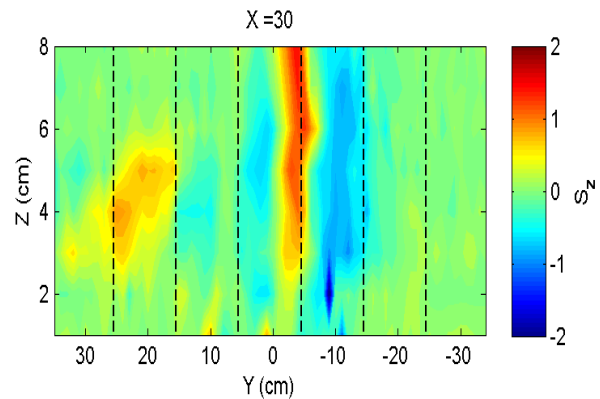
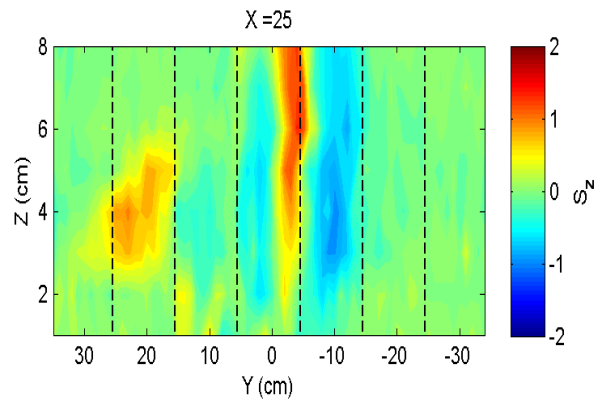
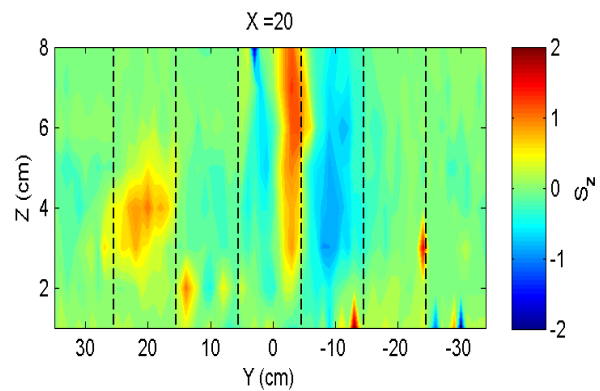
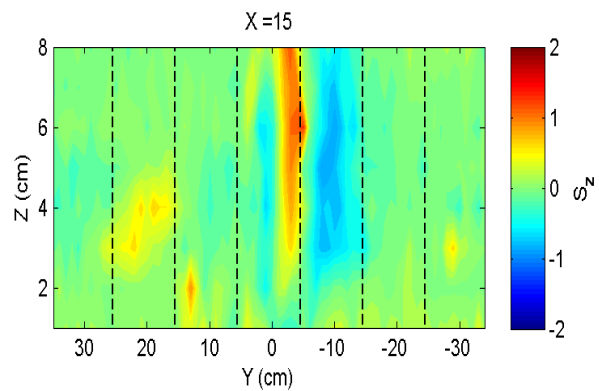


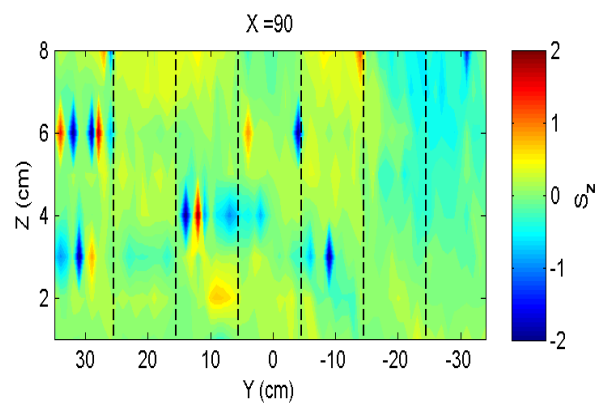
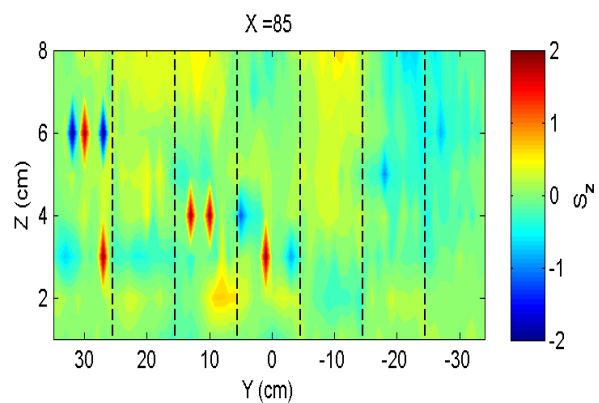
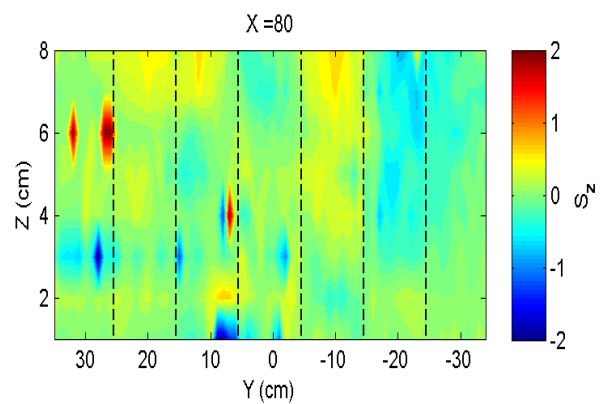
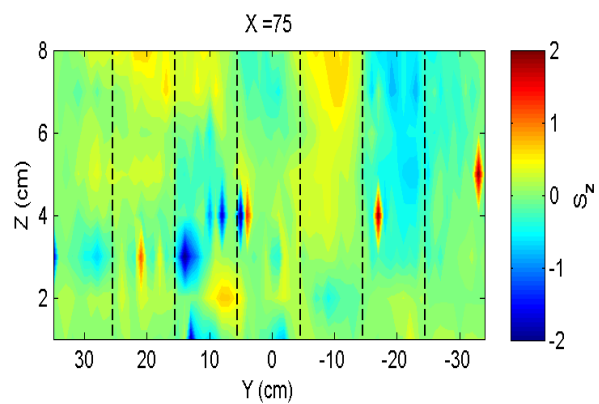
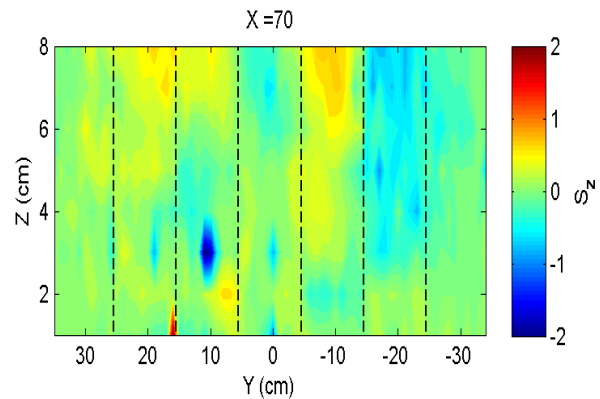
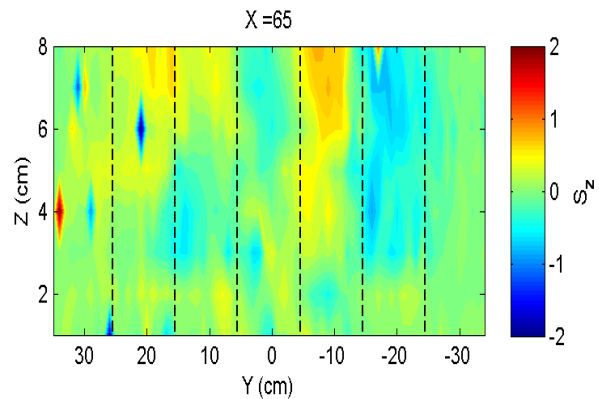
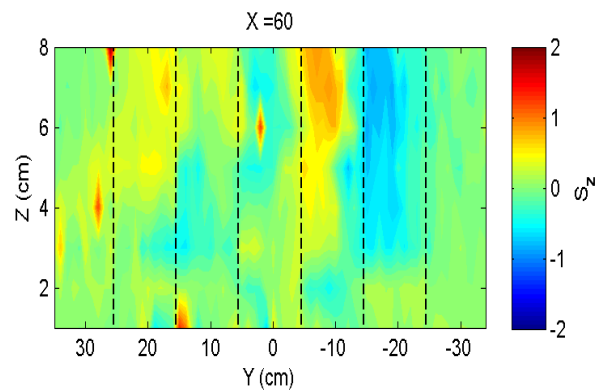
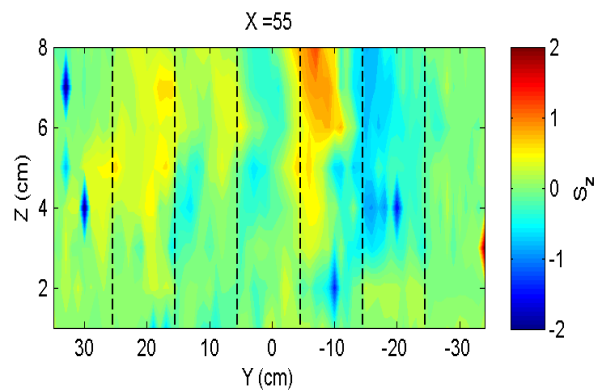


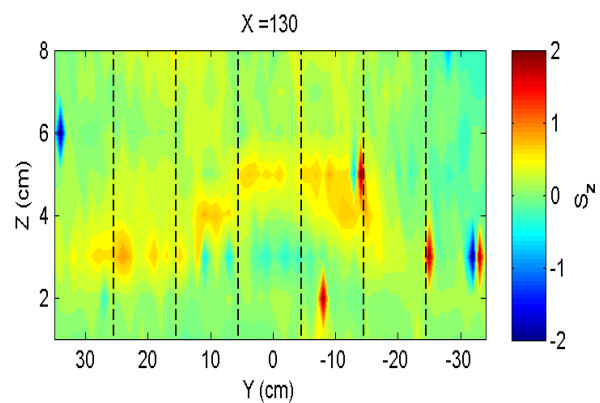
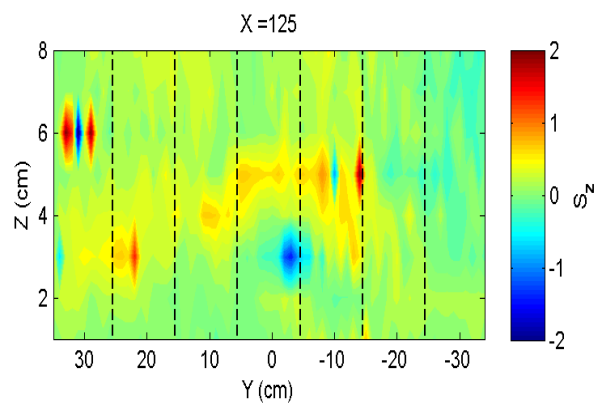
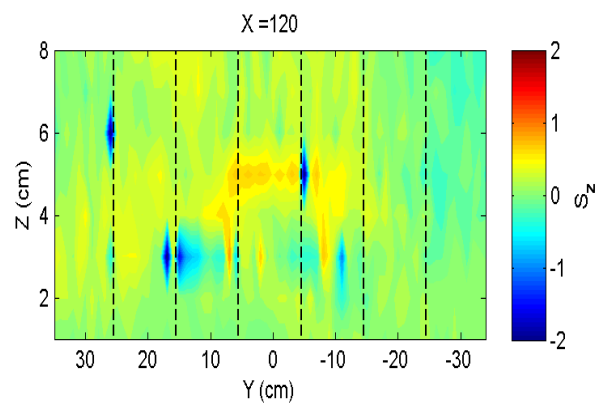
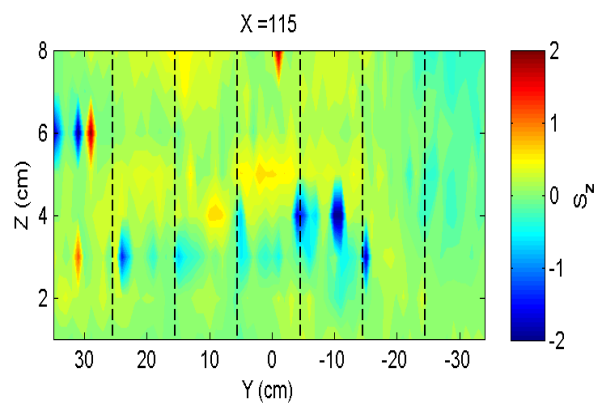
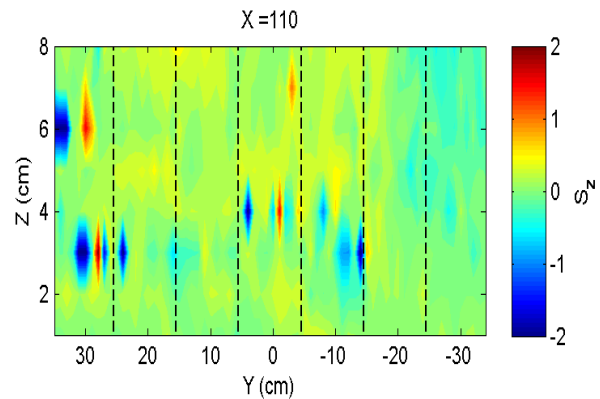
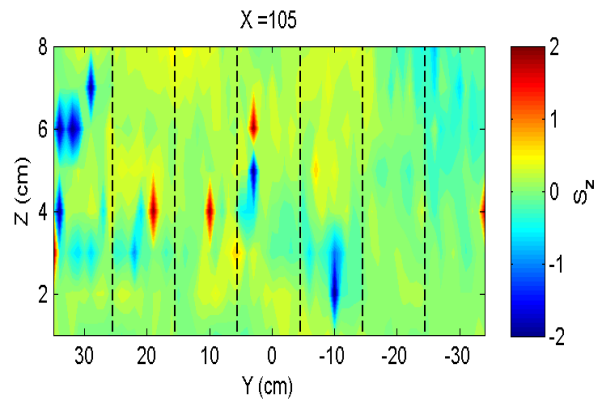
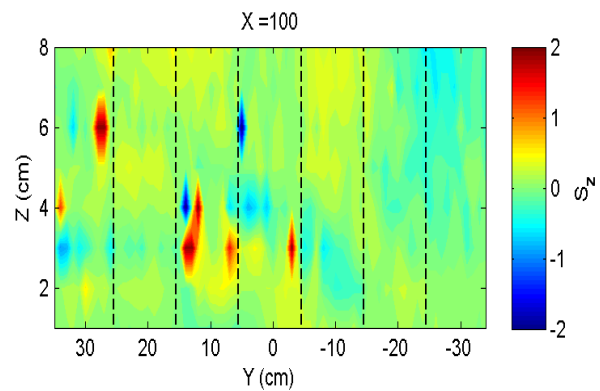
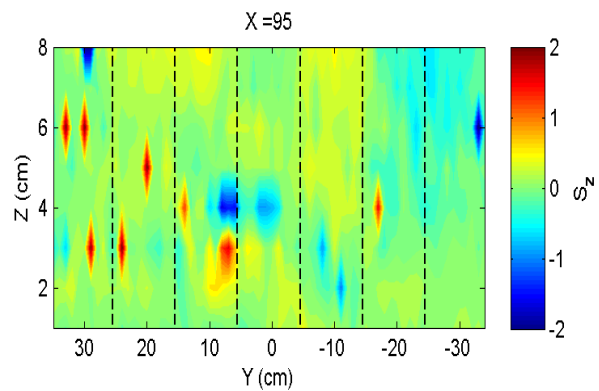


### Skewness Factor $S_z$ in y and z-Directions

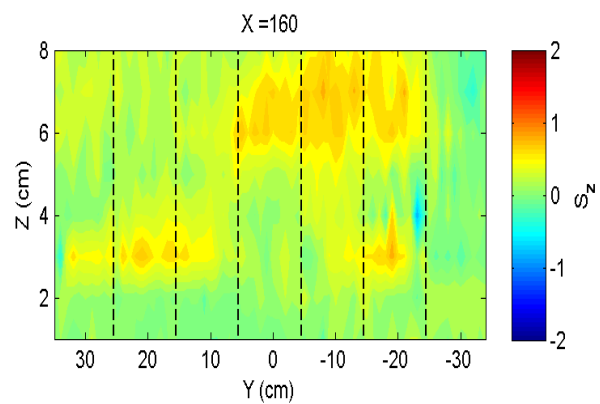
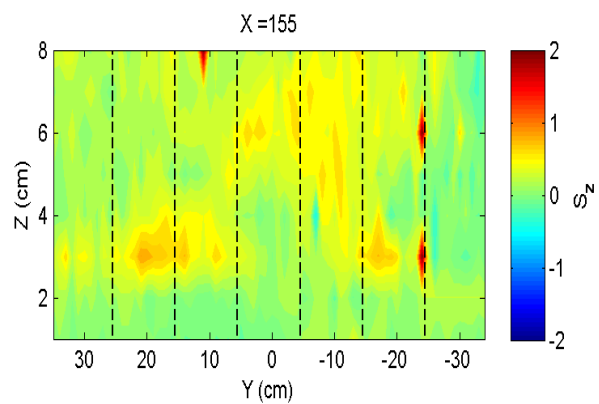
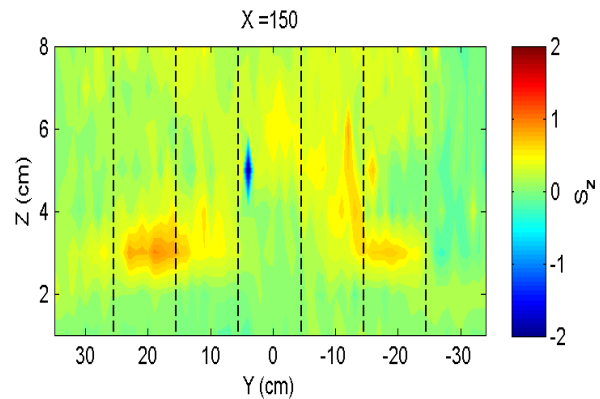
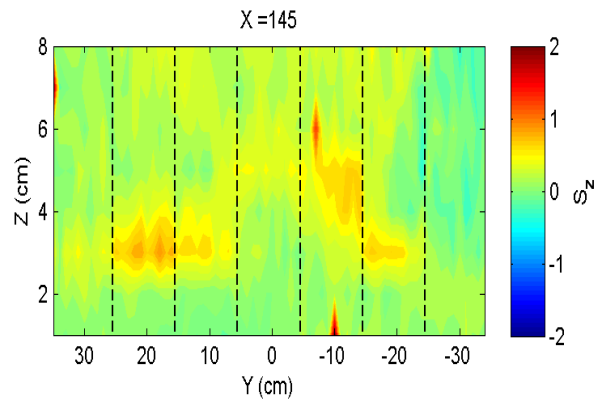
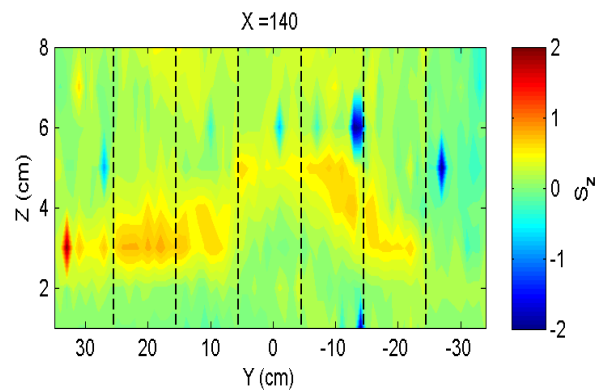
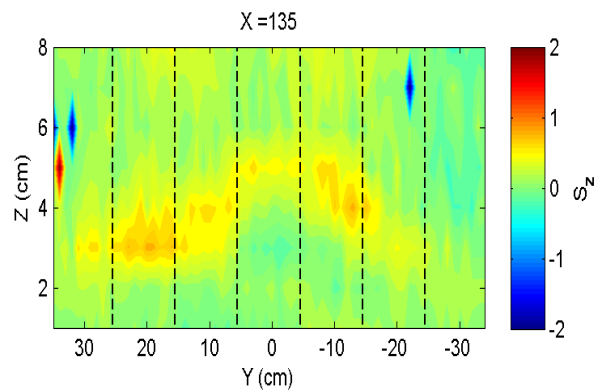




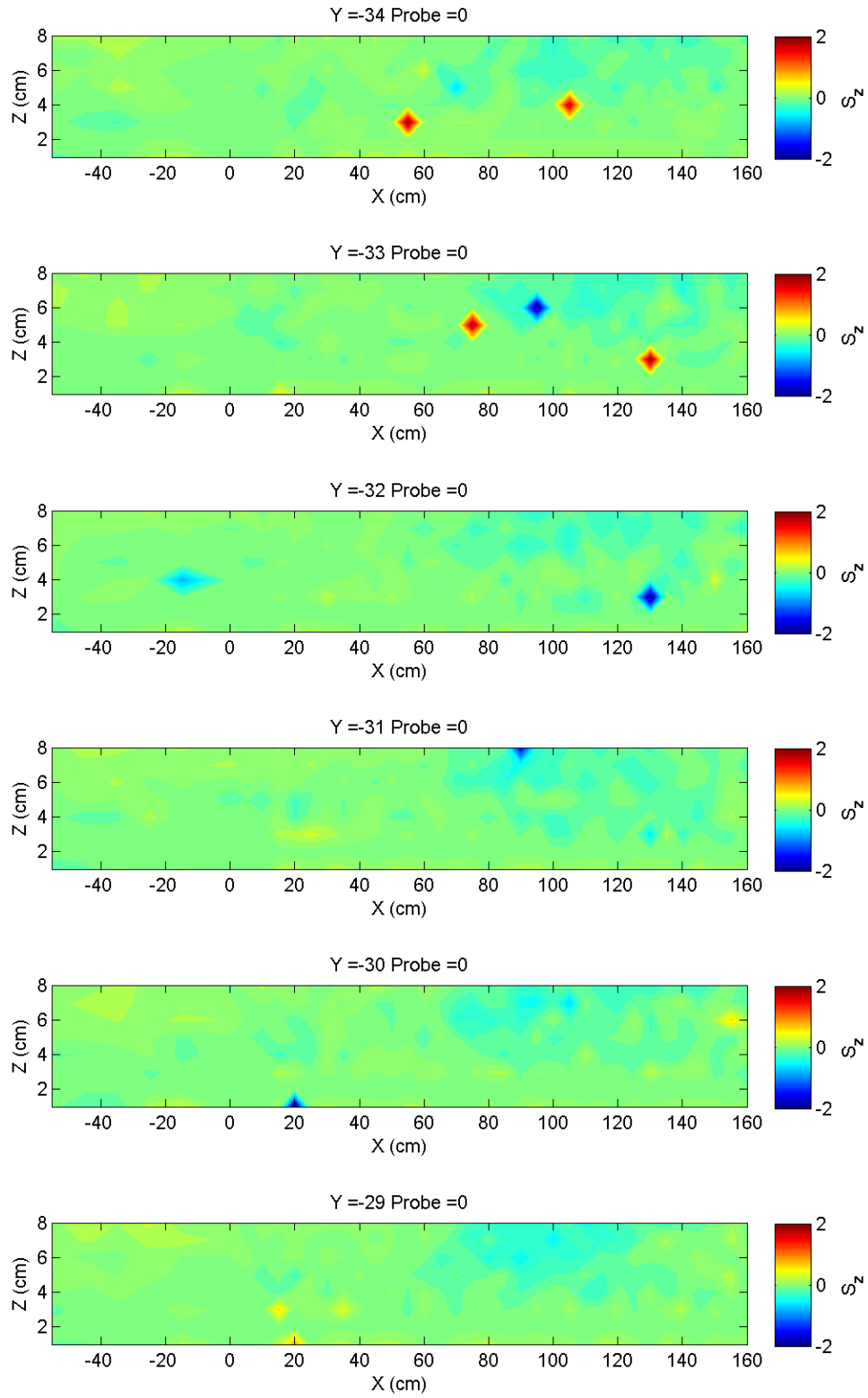




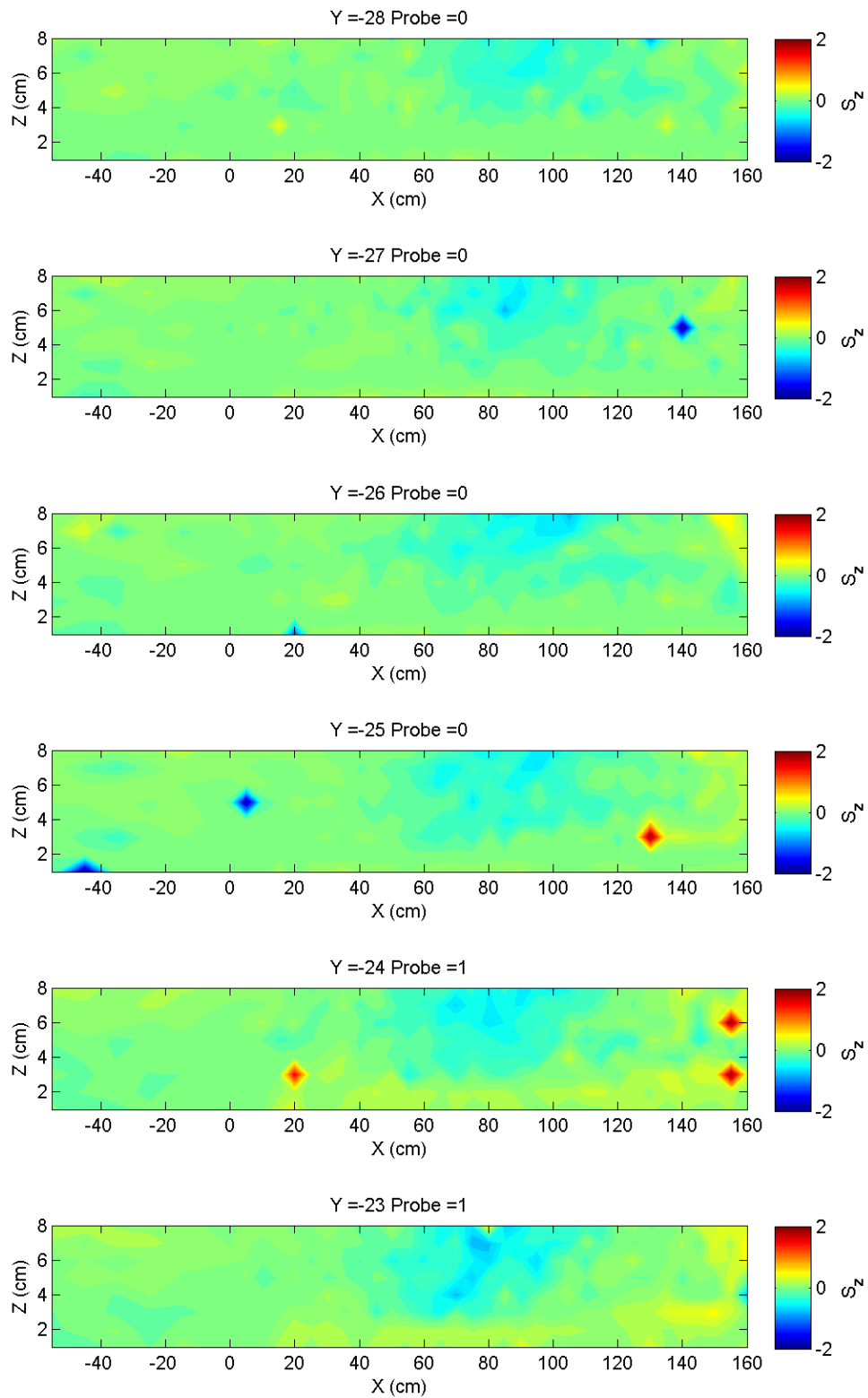


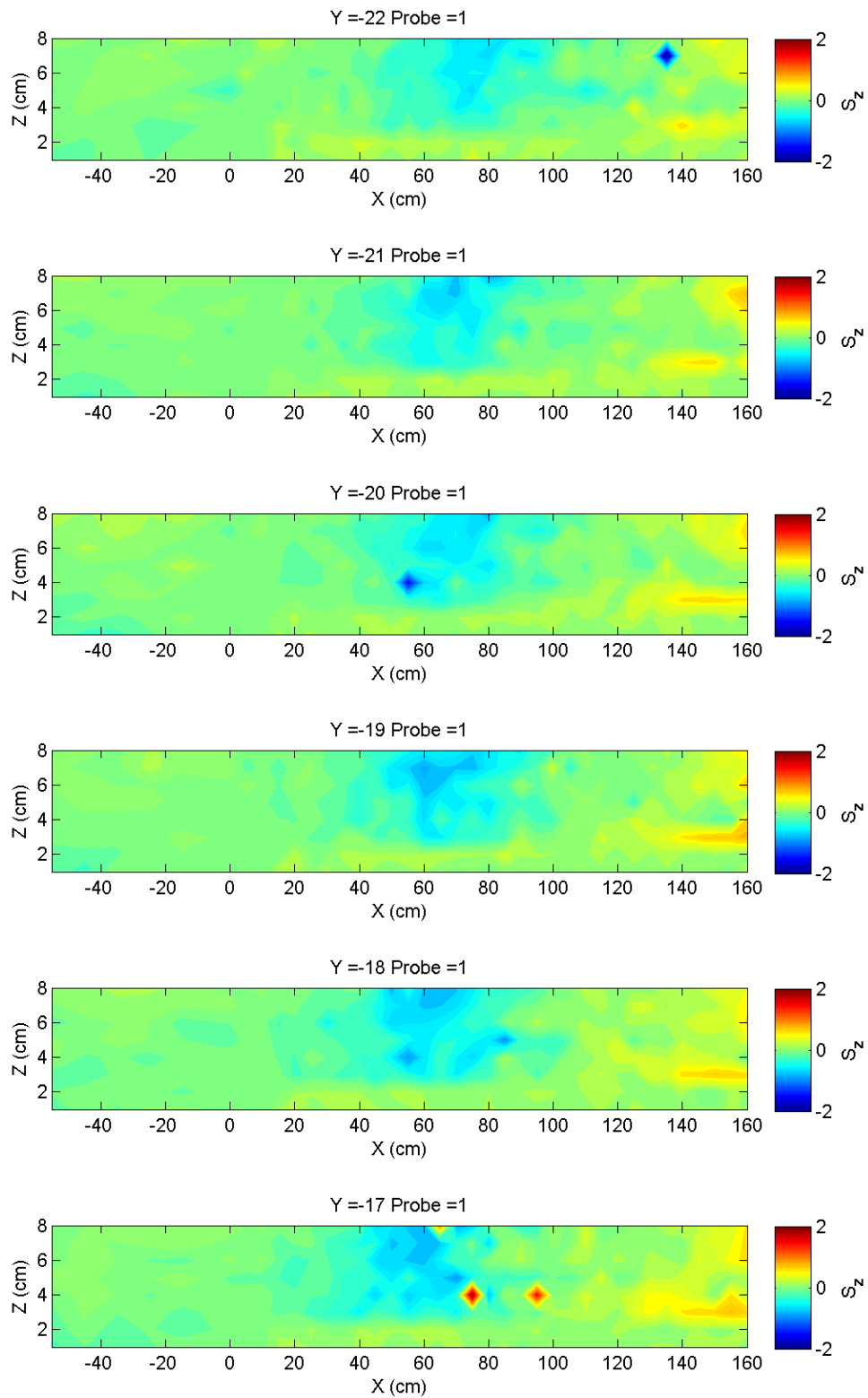


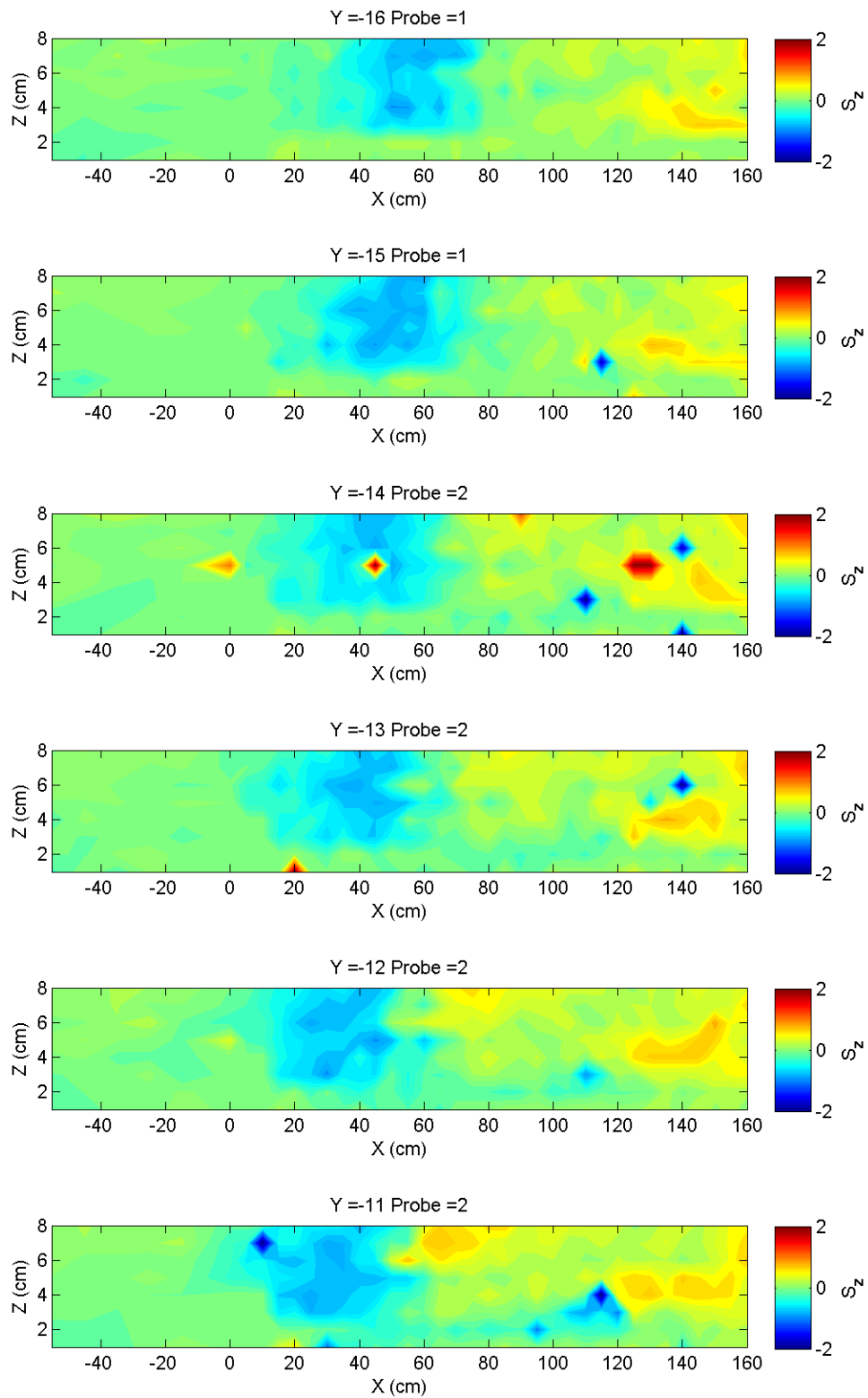
## Skewness Factor $S_z$ in x and z-Directions

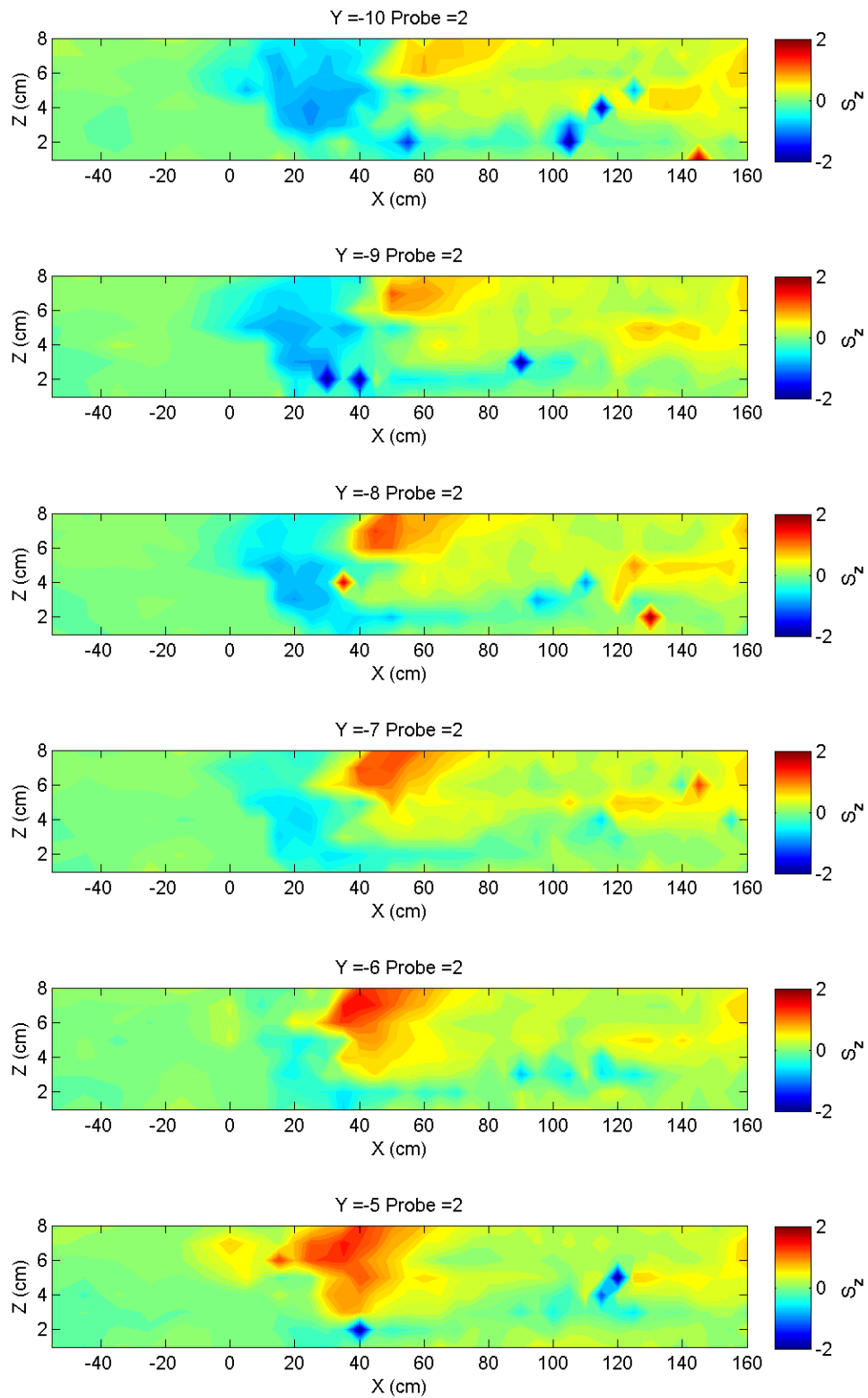


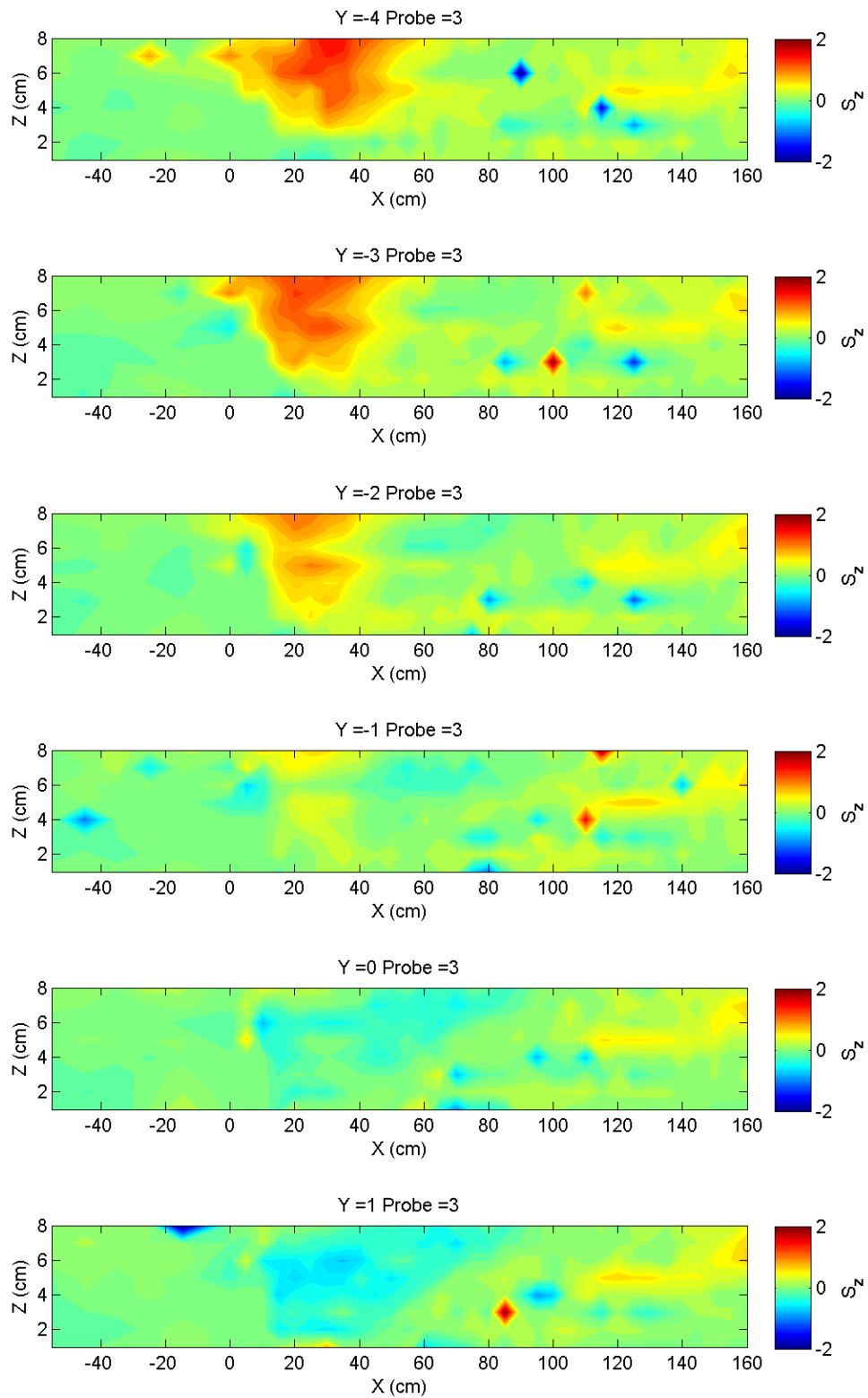


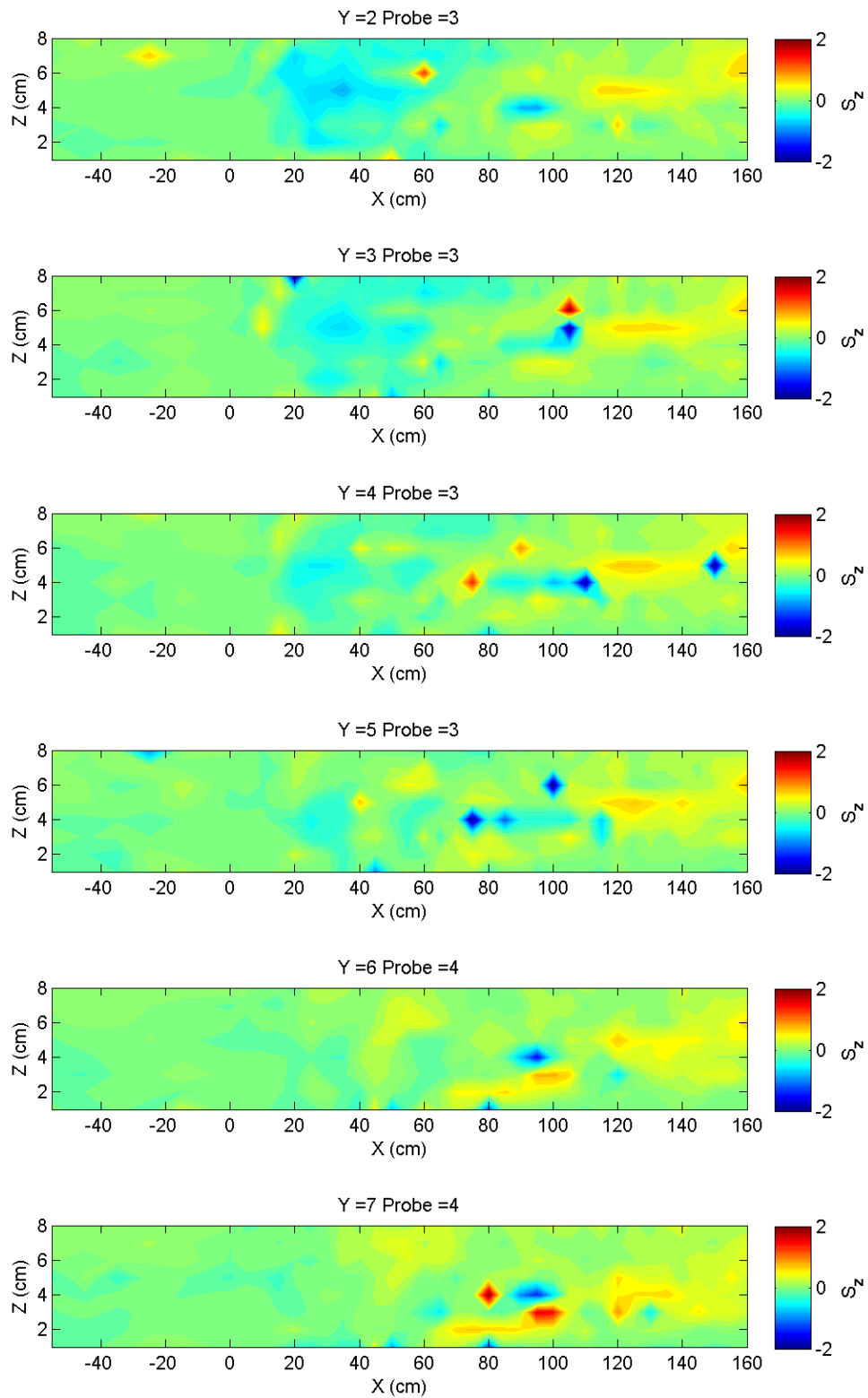


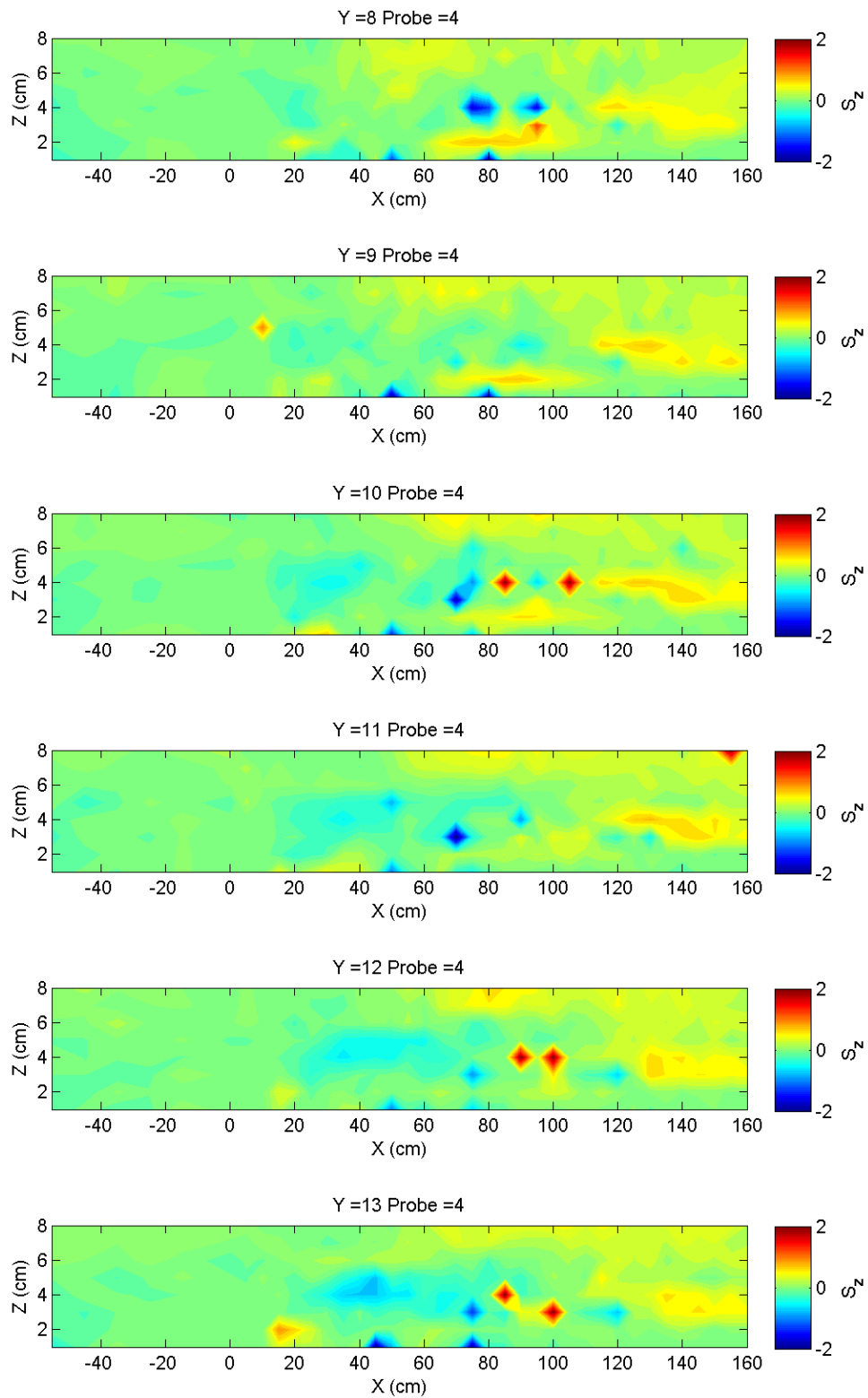


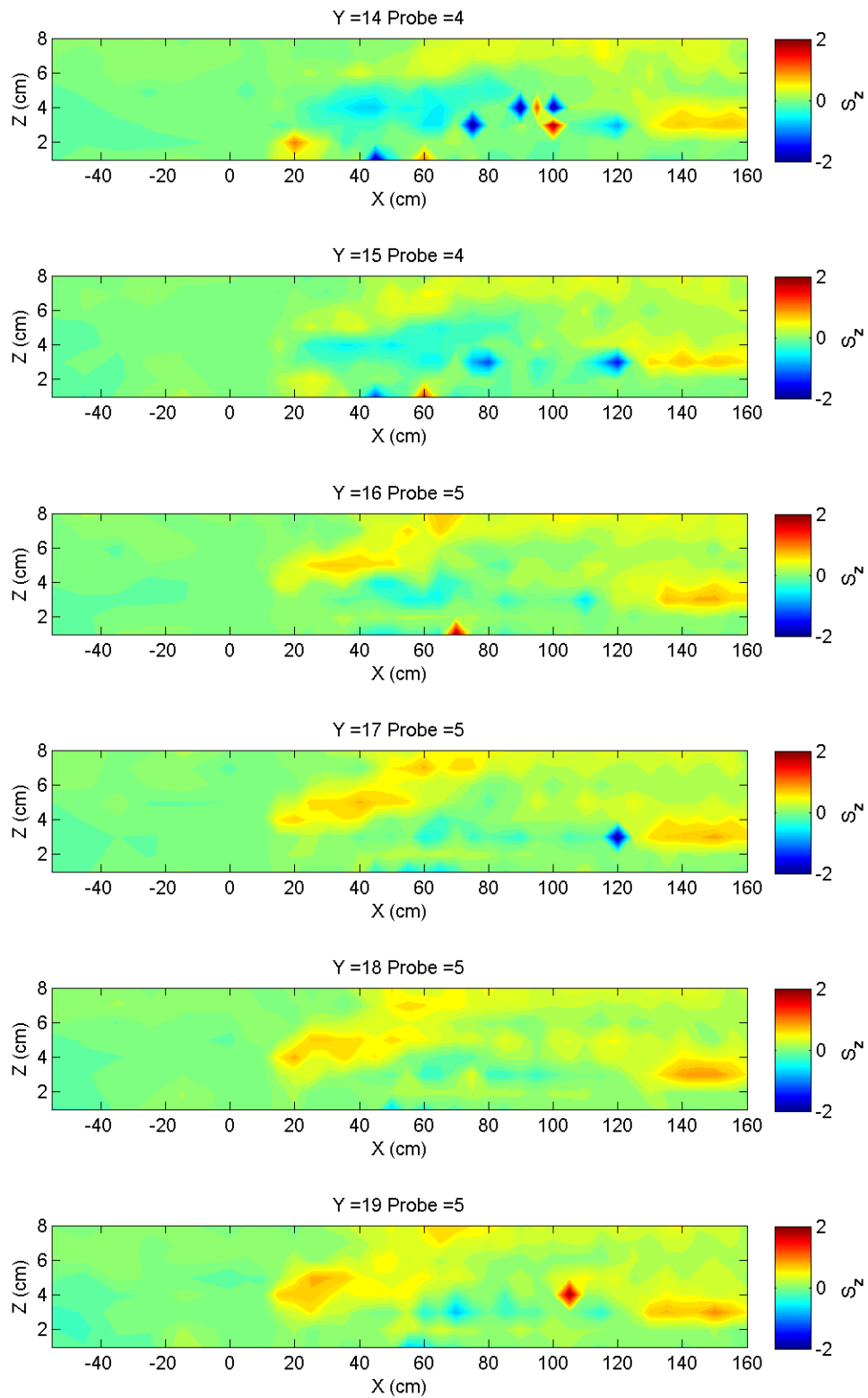




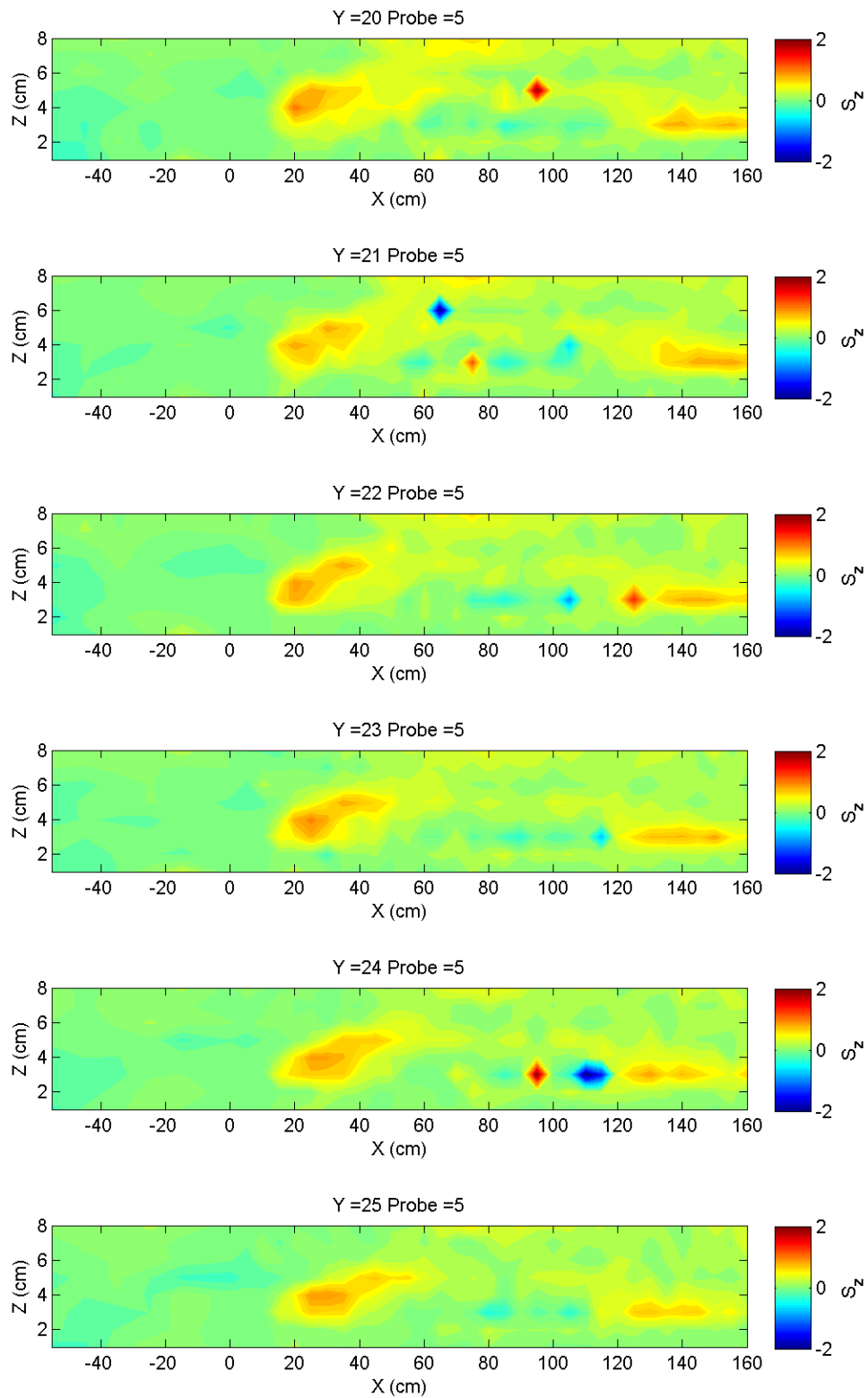


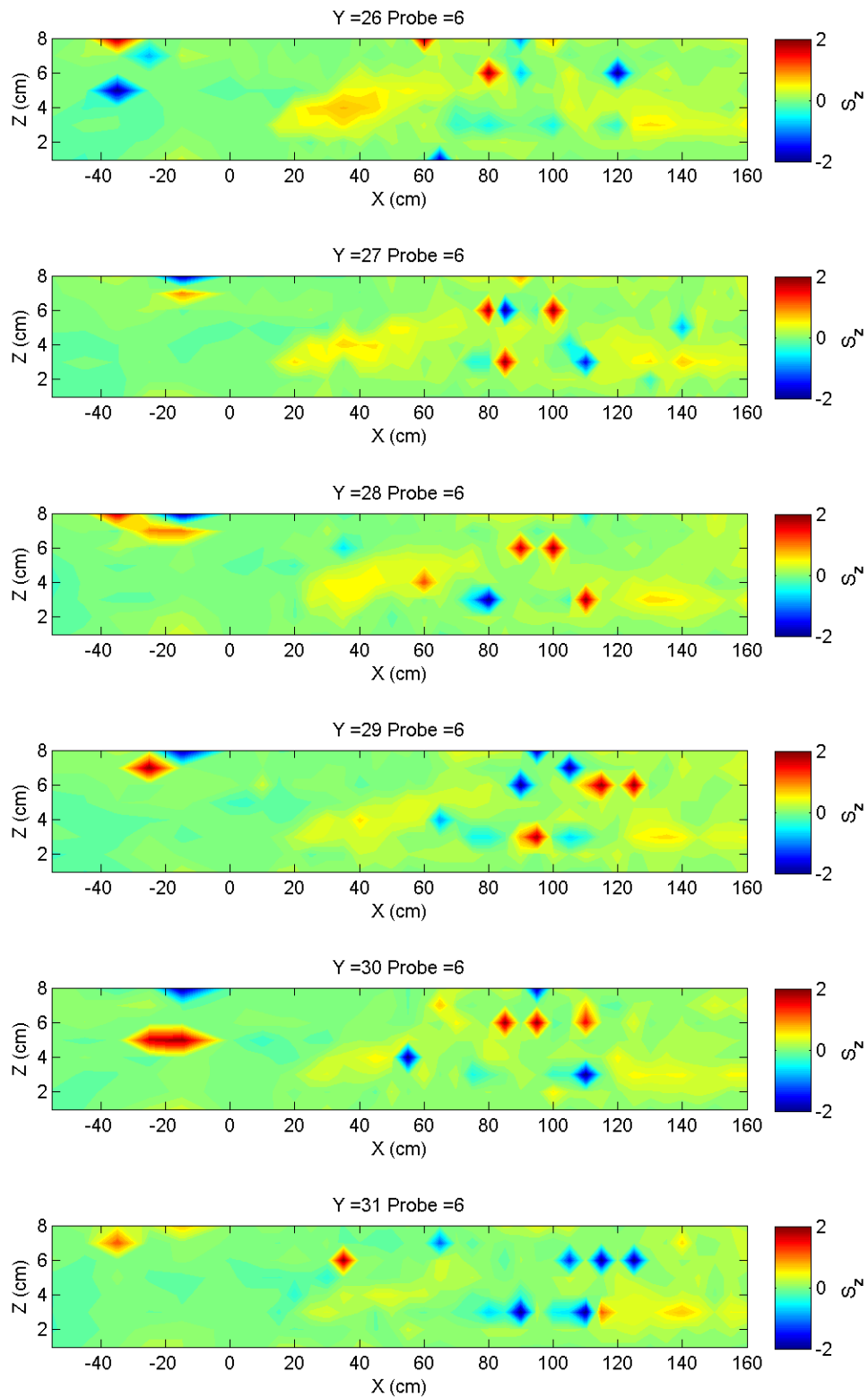


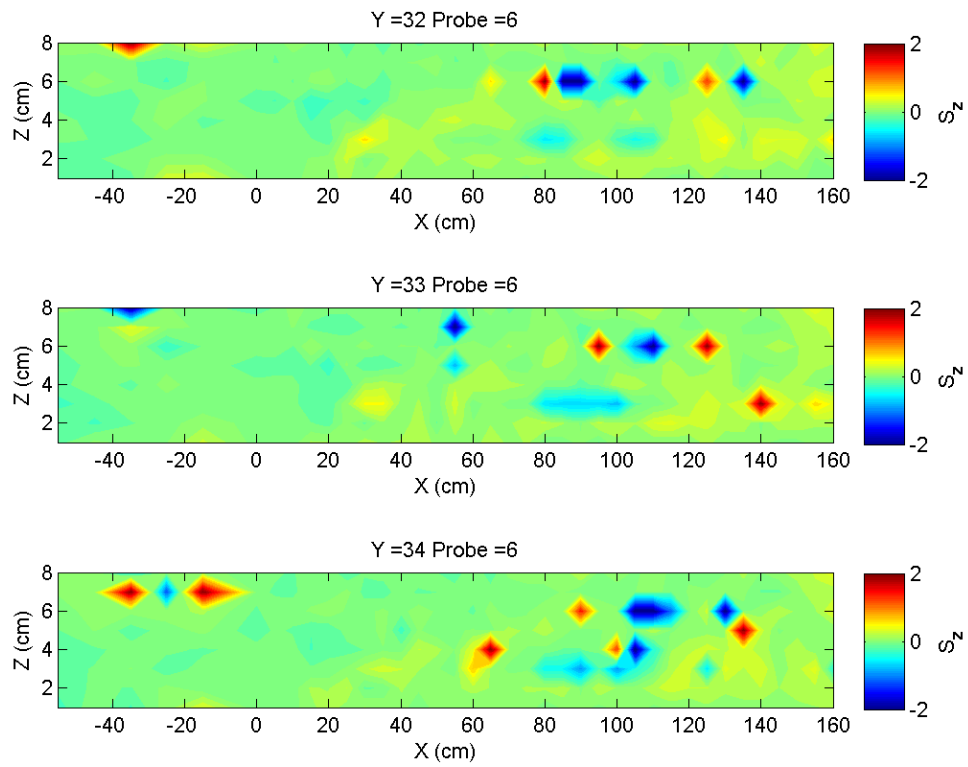






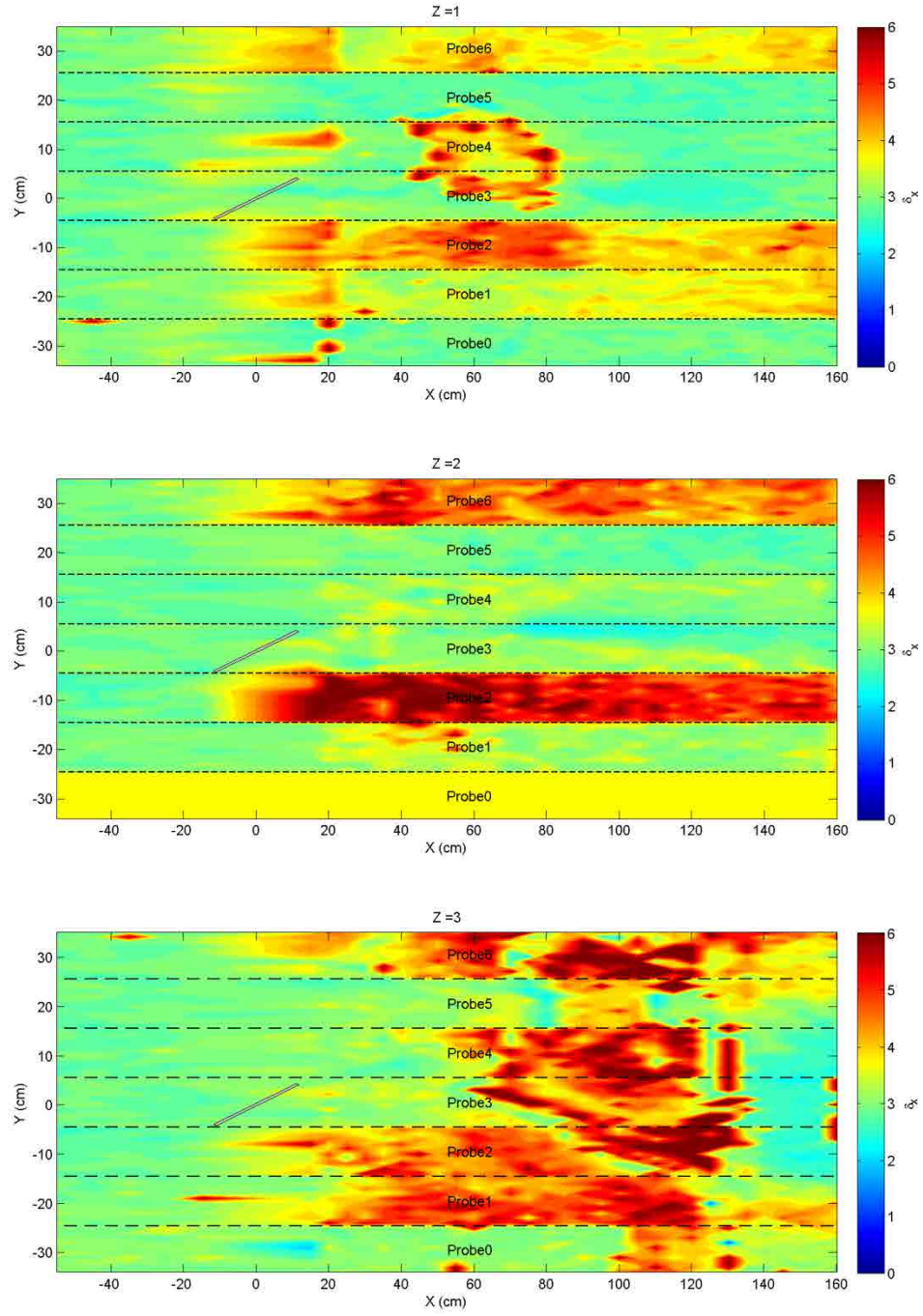


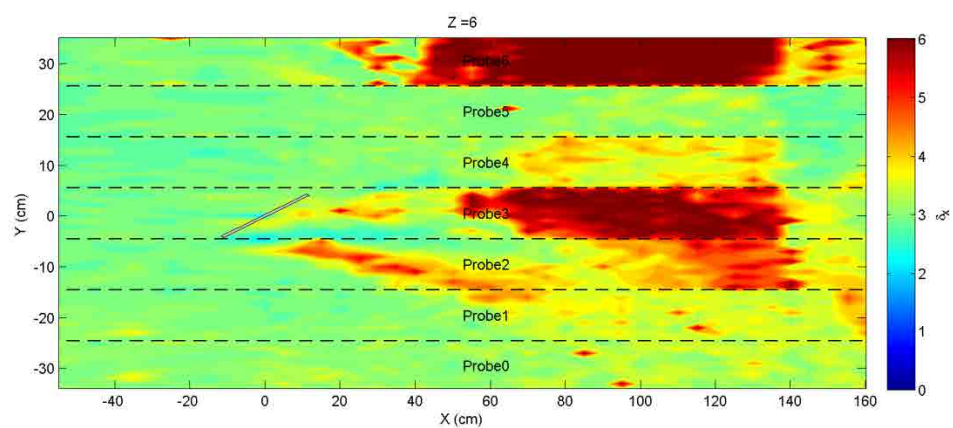
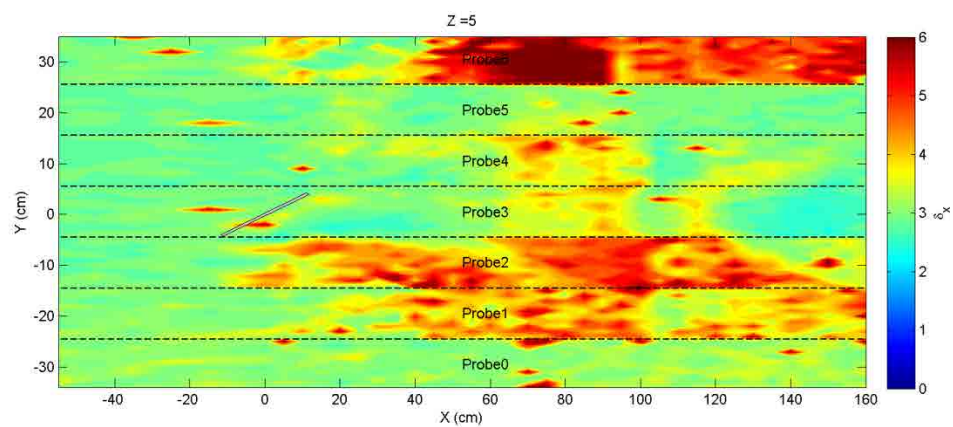
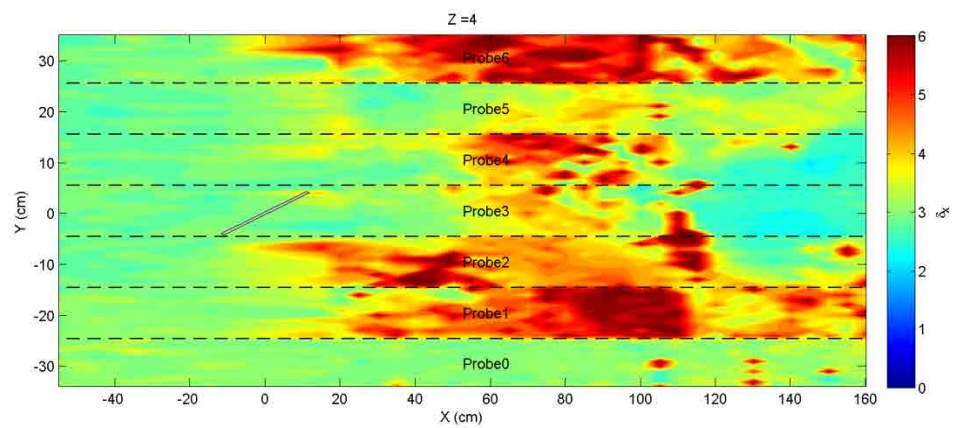




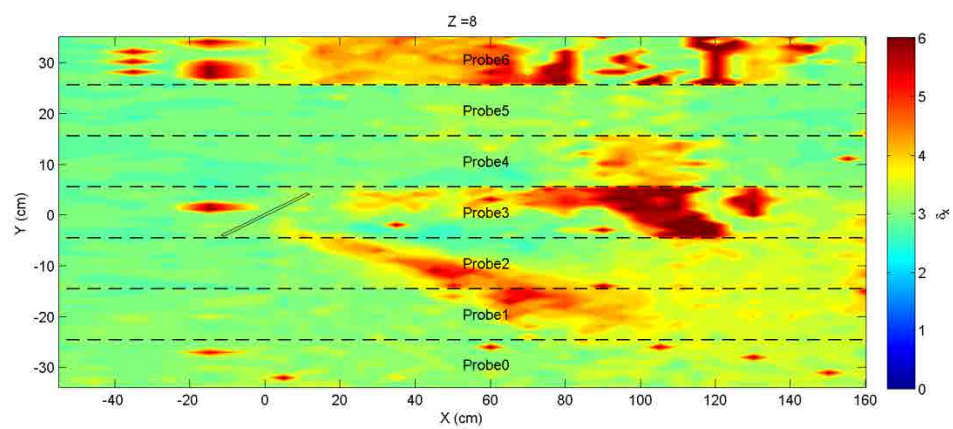
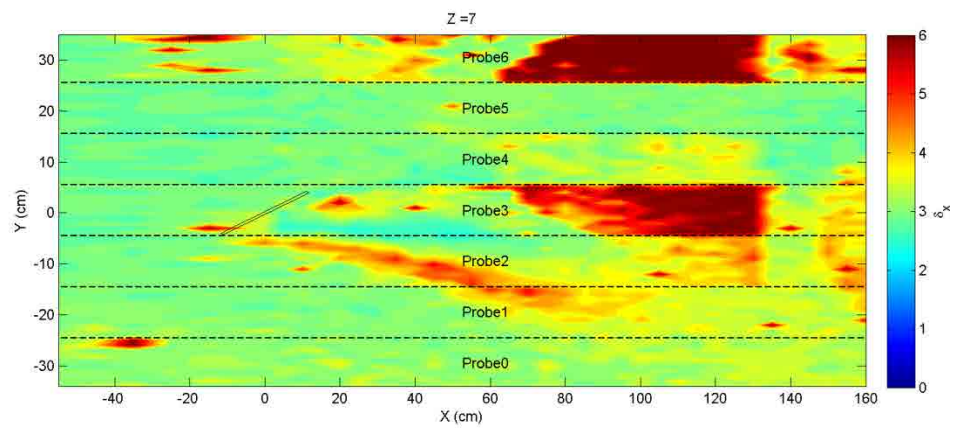
### 3. Kurtosis Factor

Kurtosis Factor  $\delta_x$  in x and y-Directions

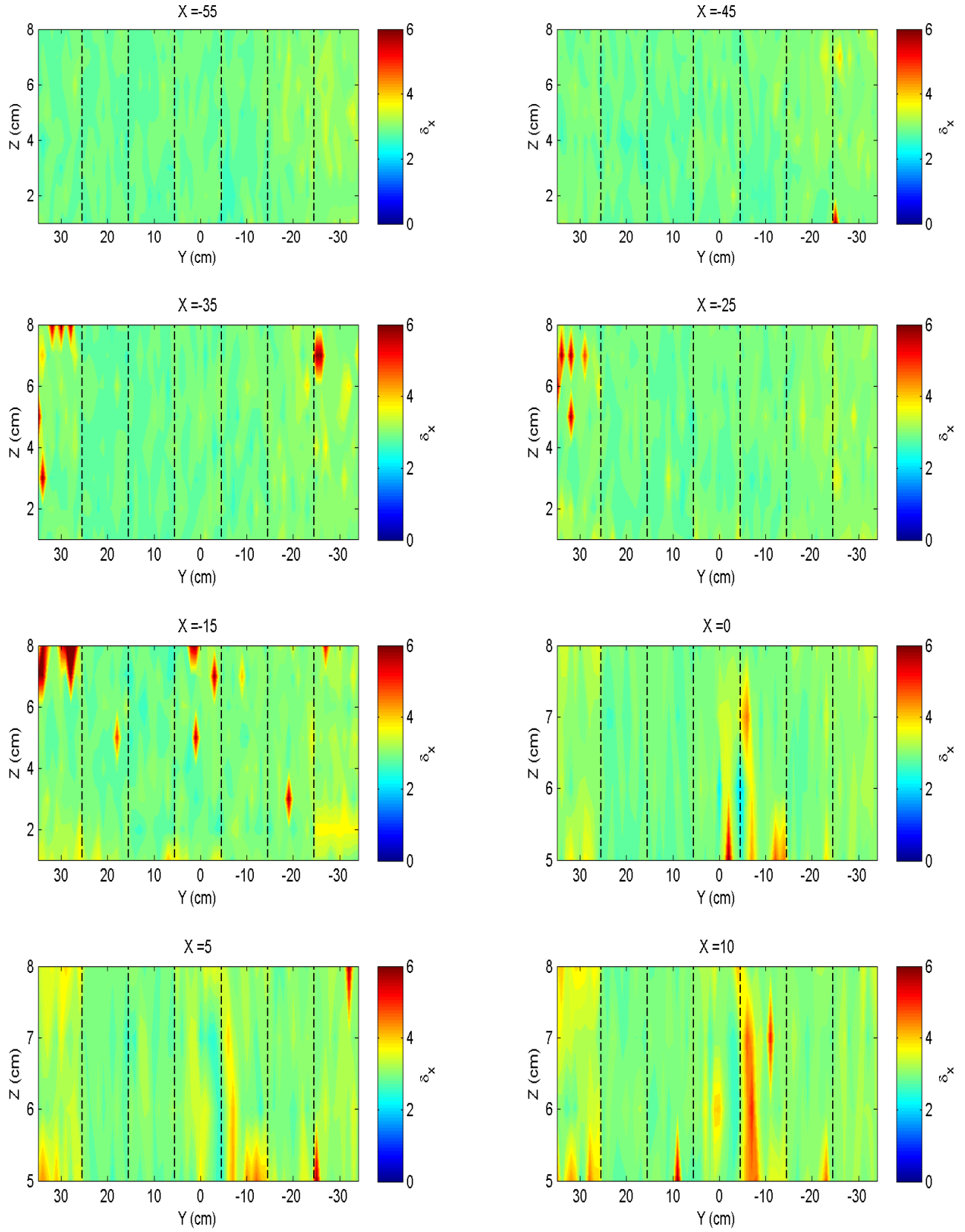


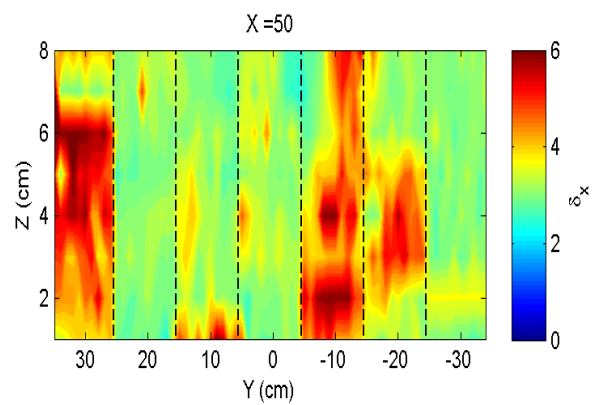
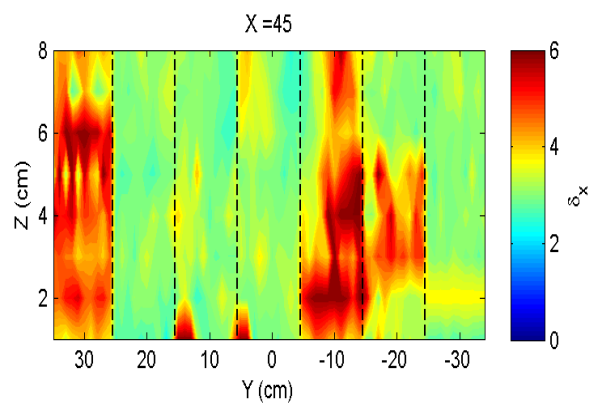
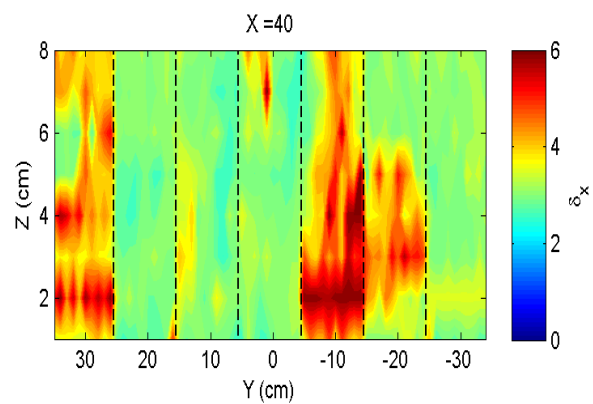
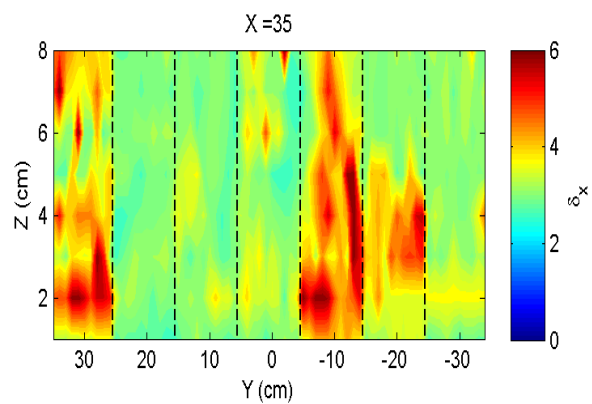
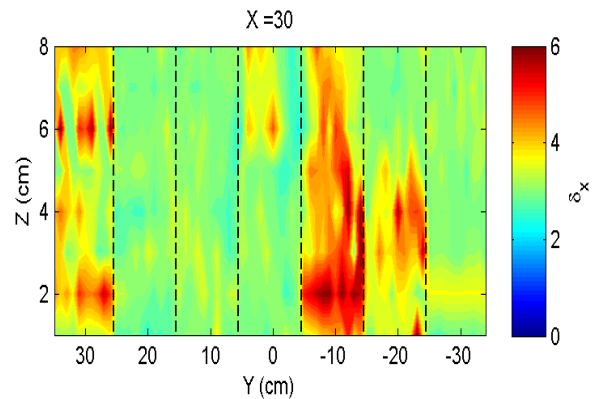
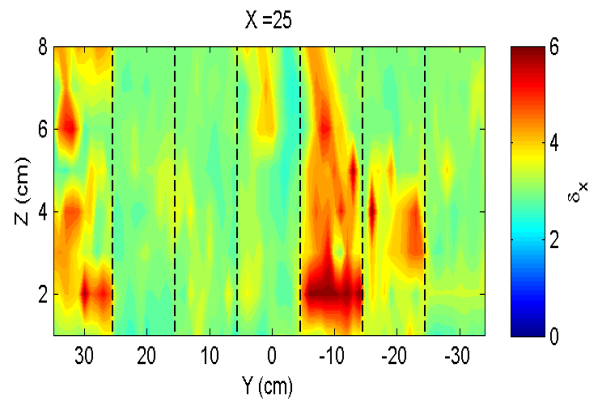
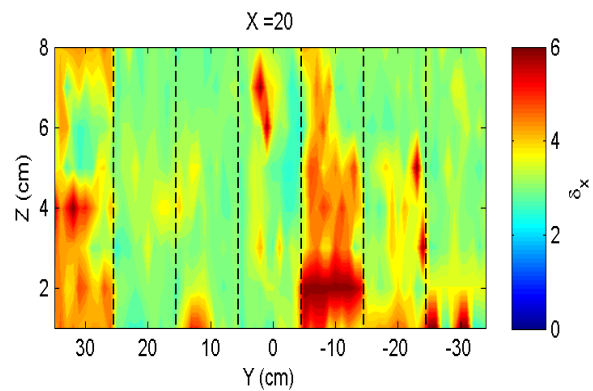
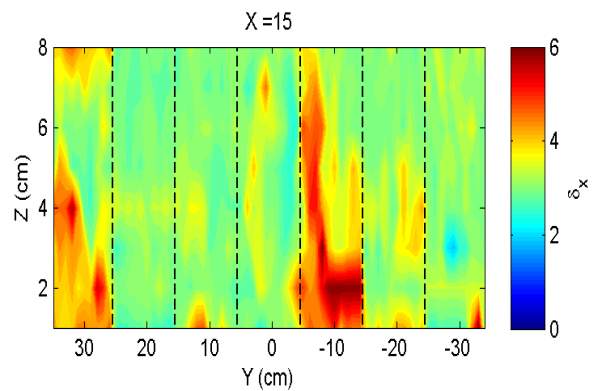




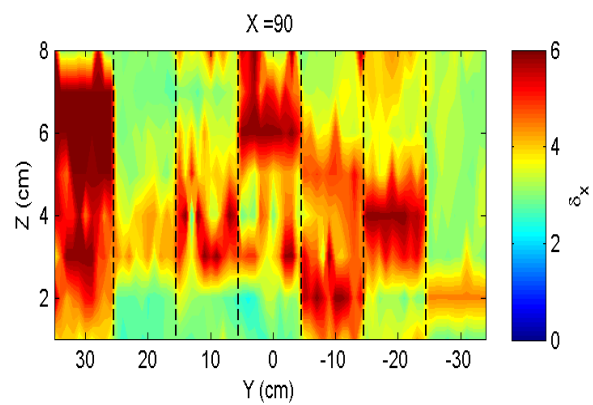
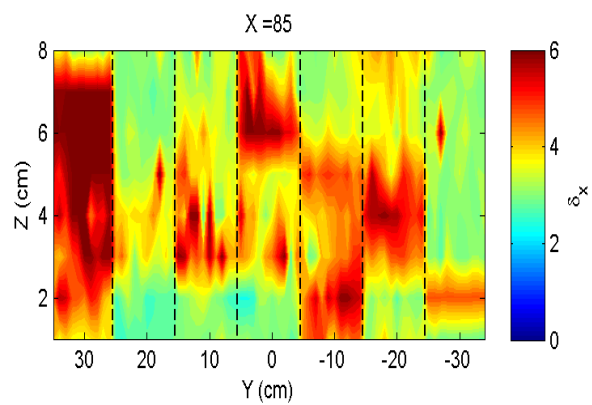
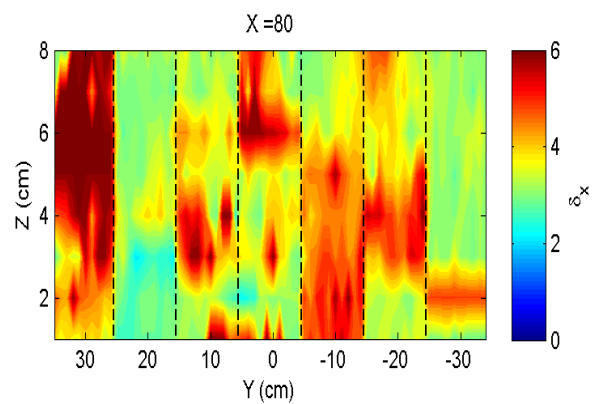
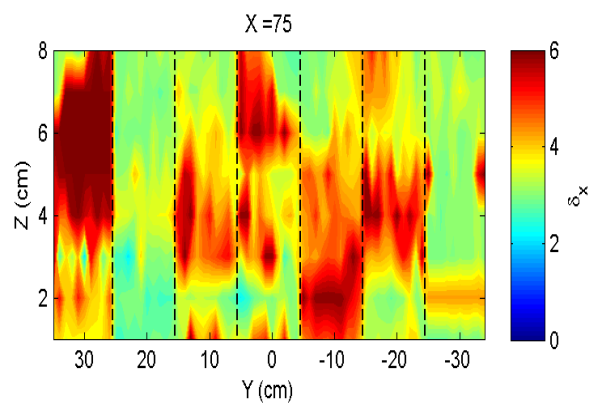
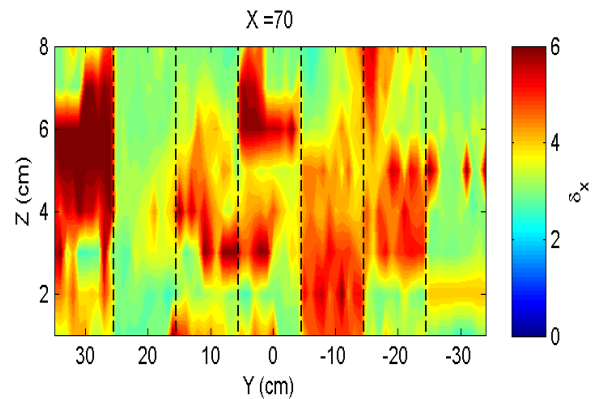
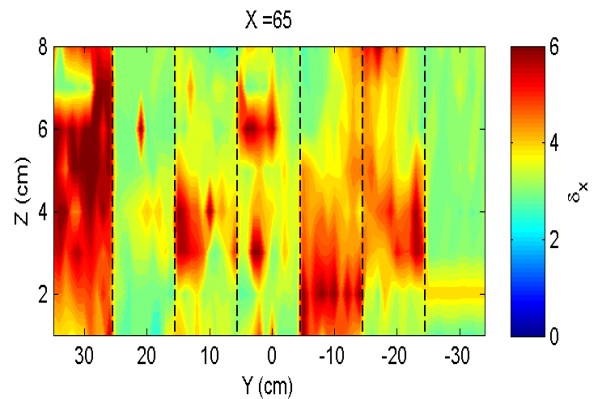
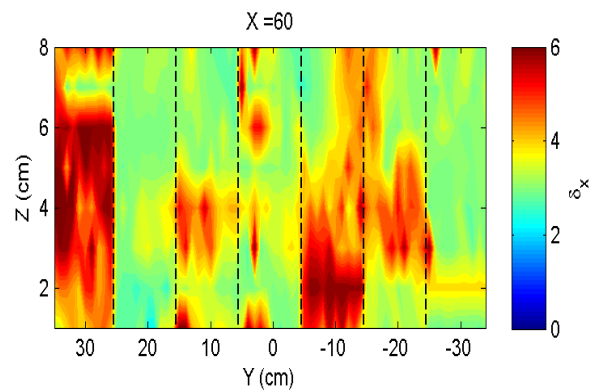
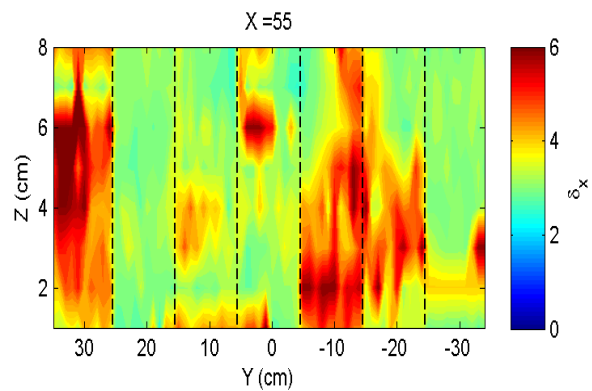


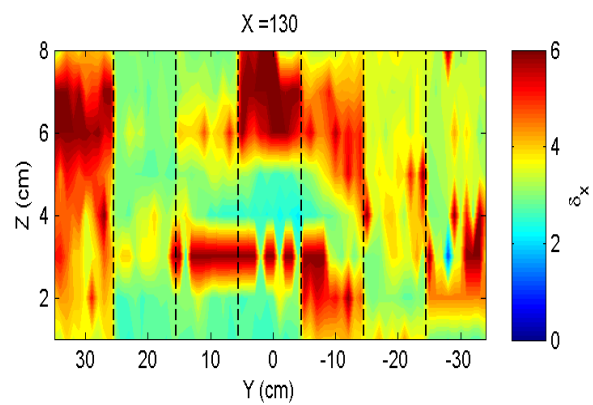
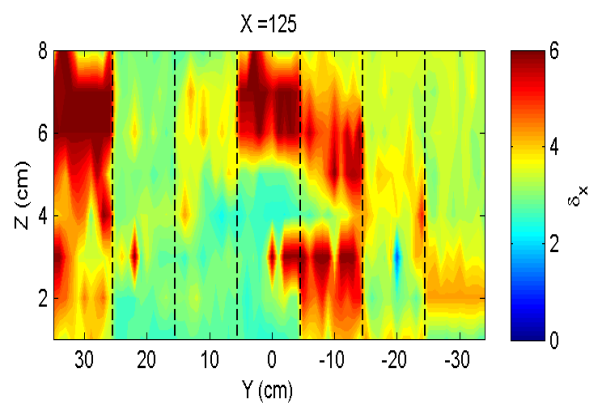
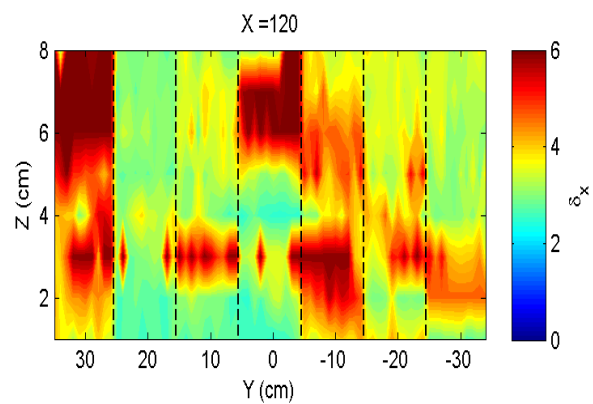
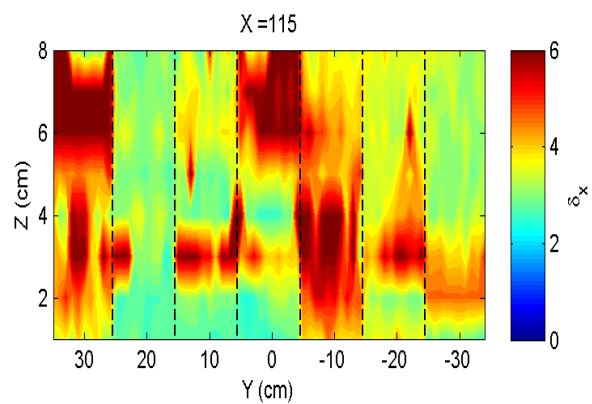
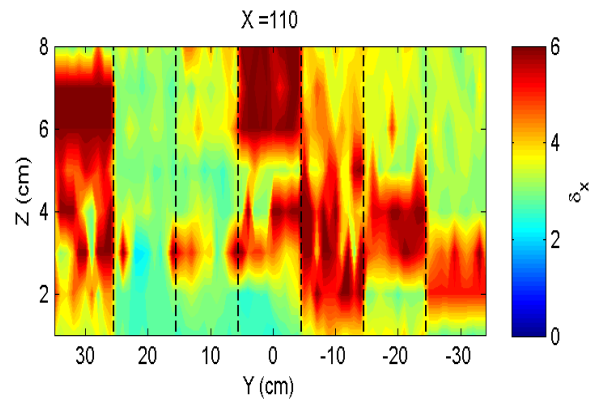
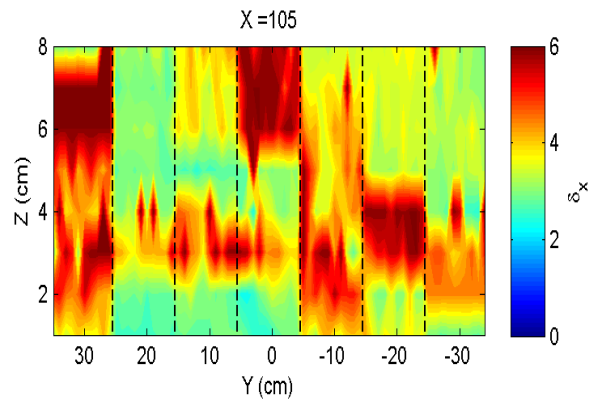
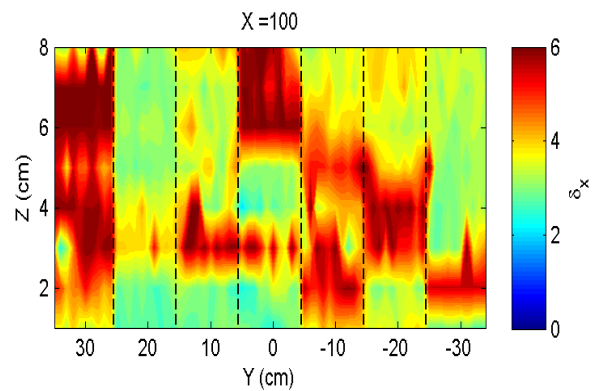
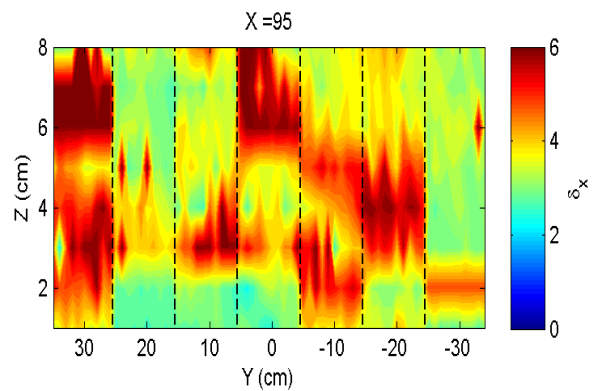
### Kurtosis Factor $\delta_x$ in y and z-Directions

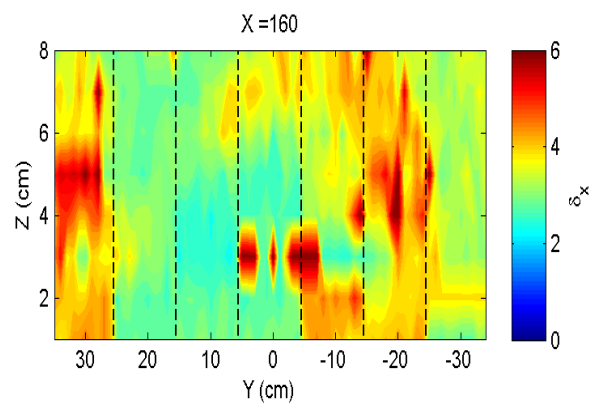
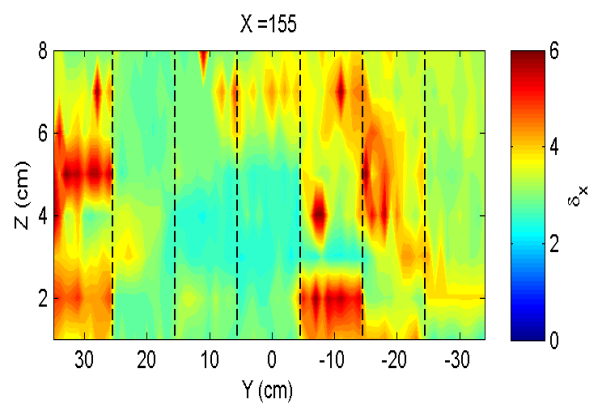
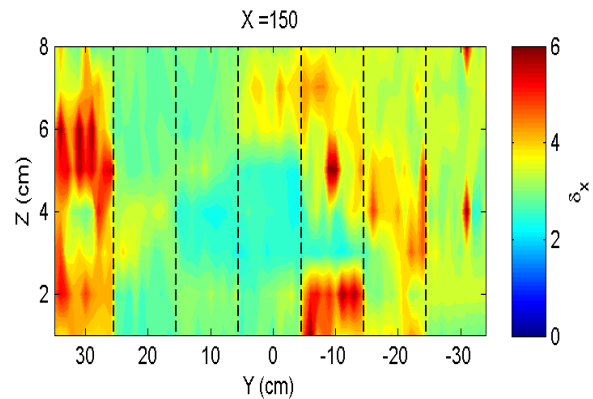
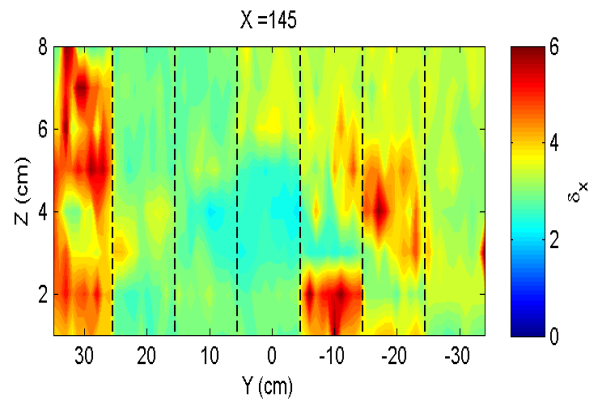
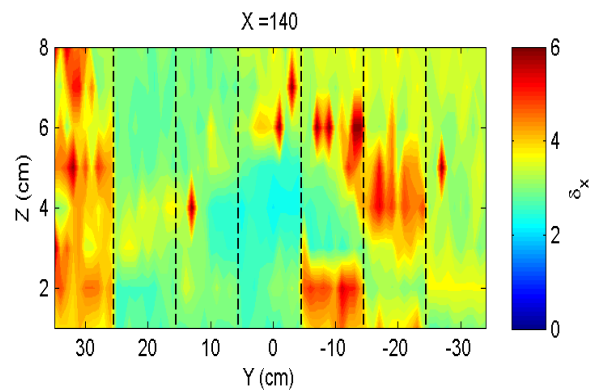
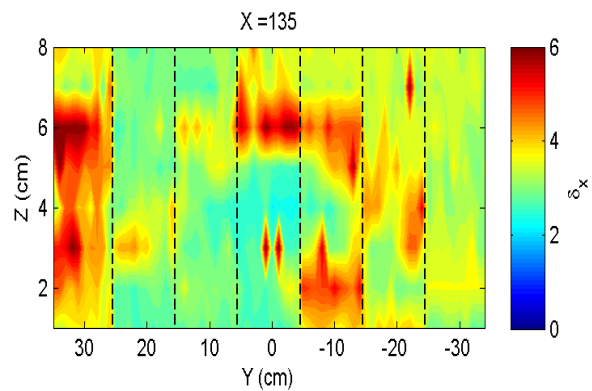




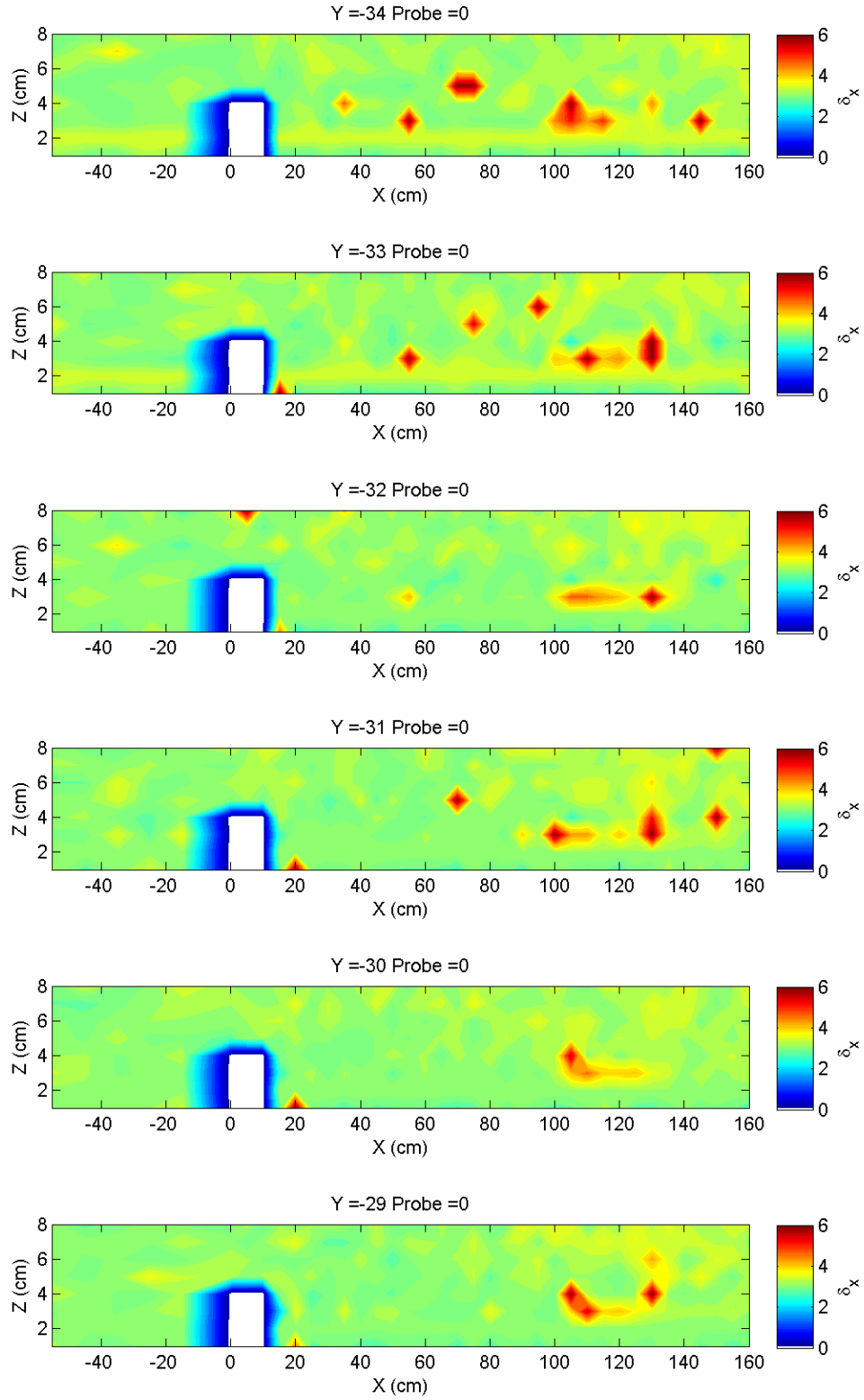


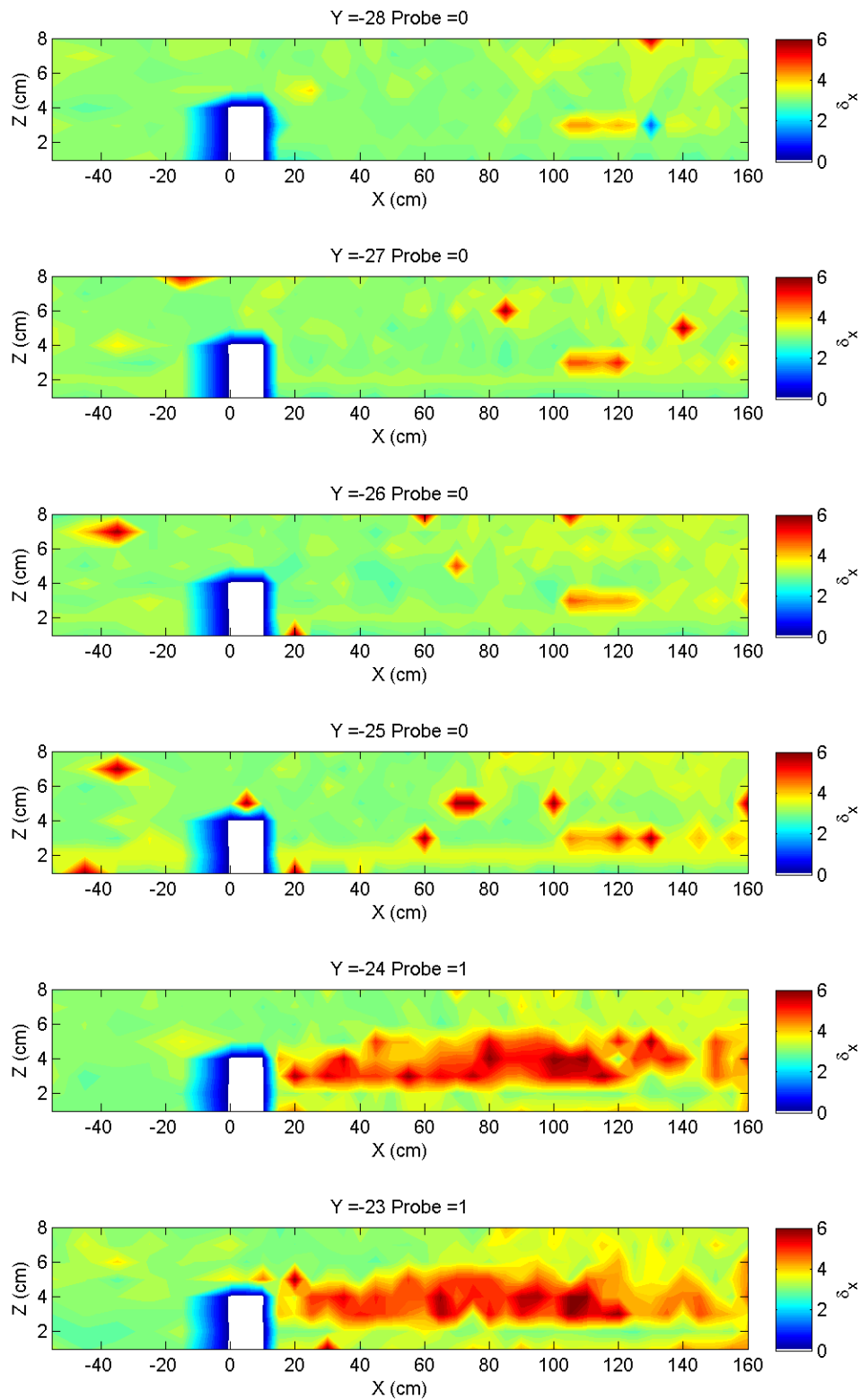


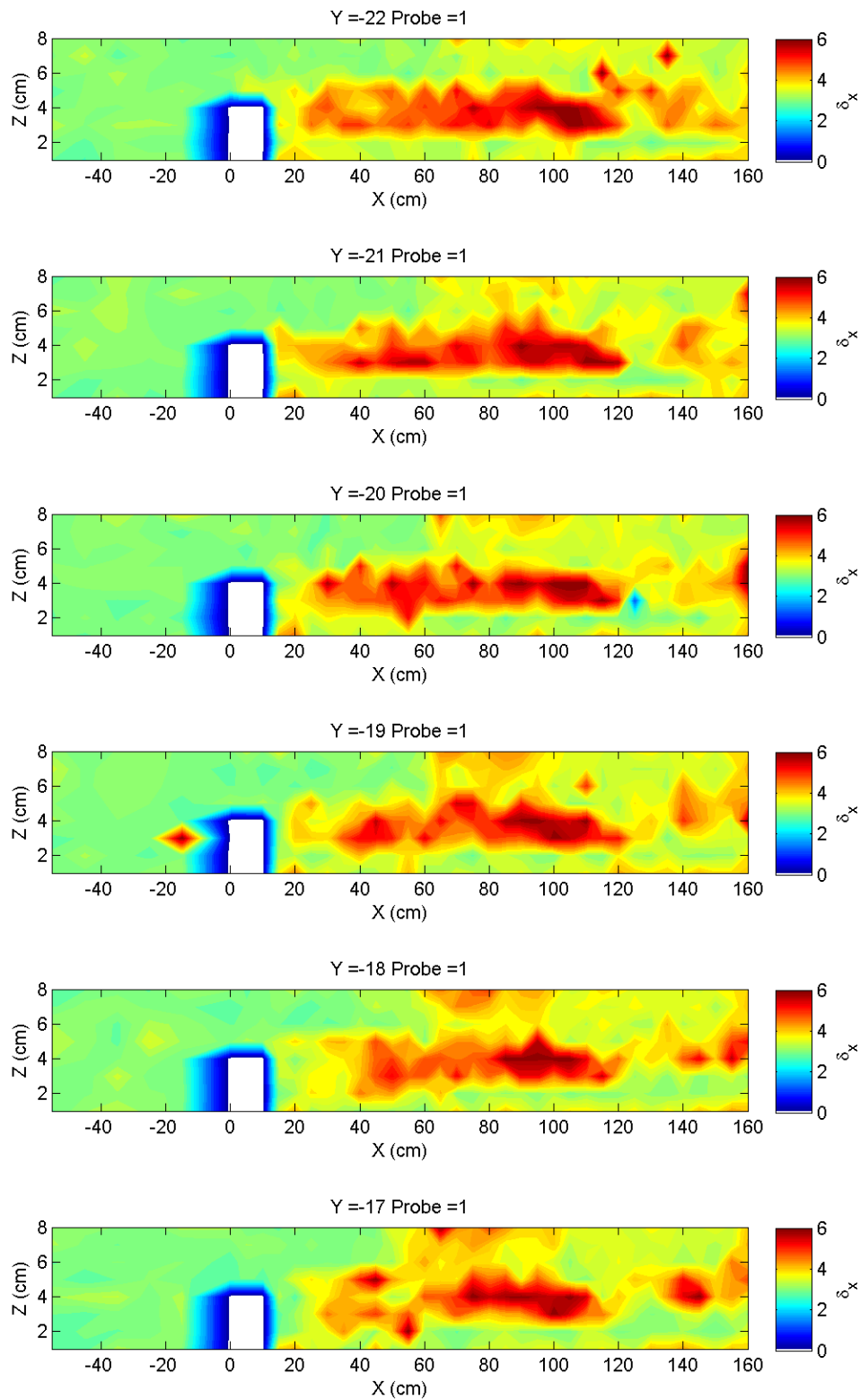


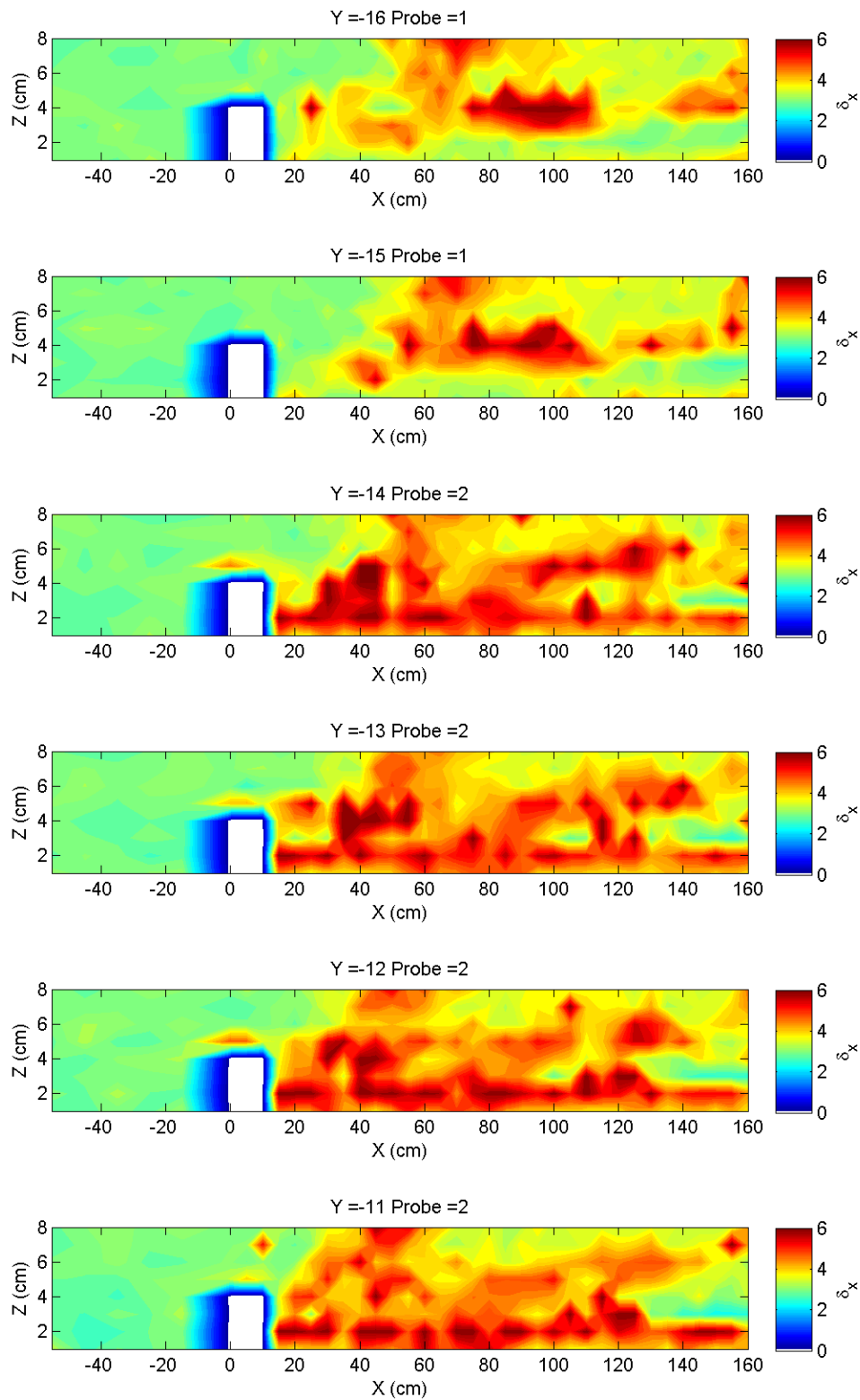


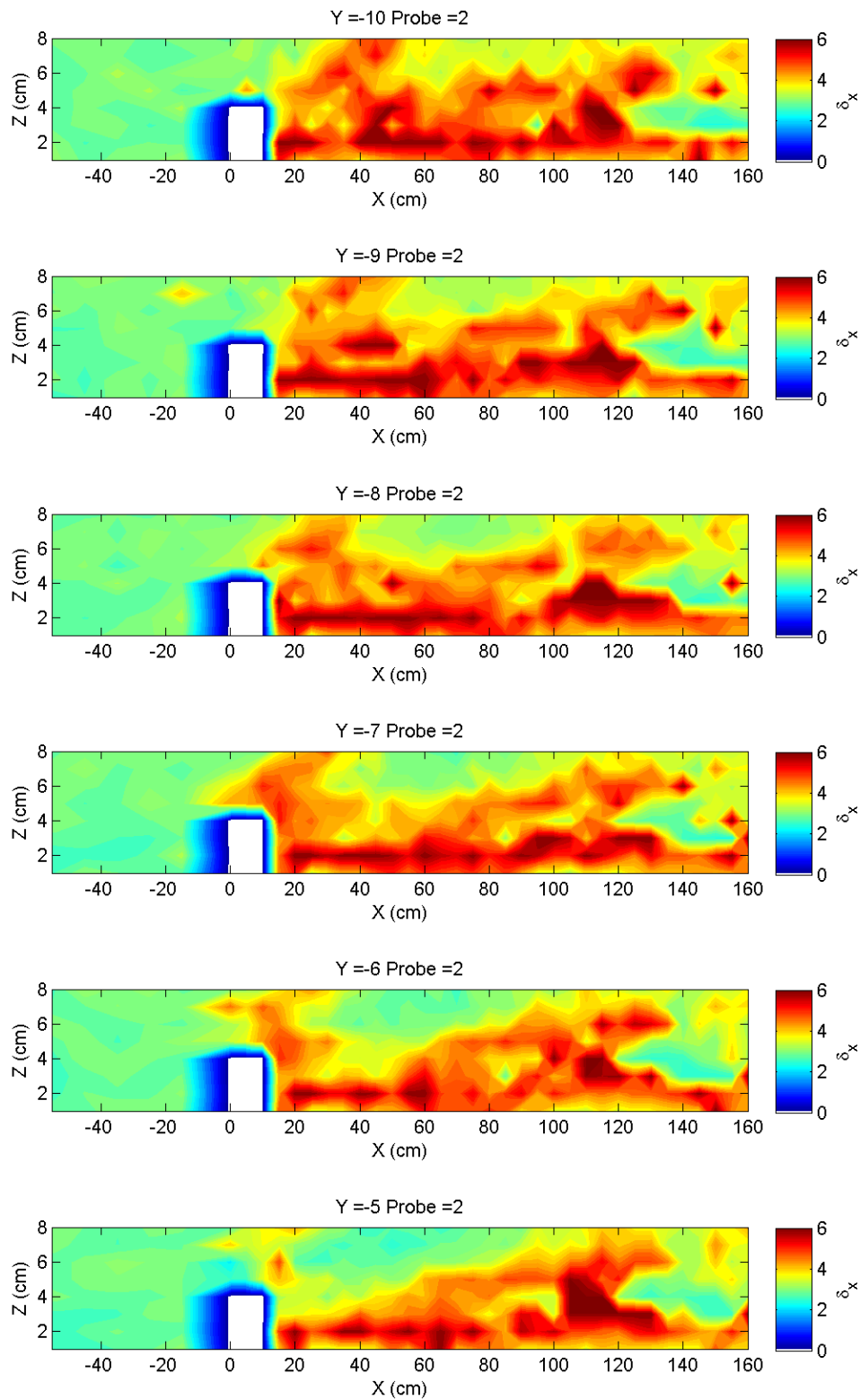
## Kurtosis Factor $\delta_x$ in x and z-Directions



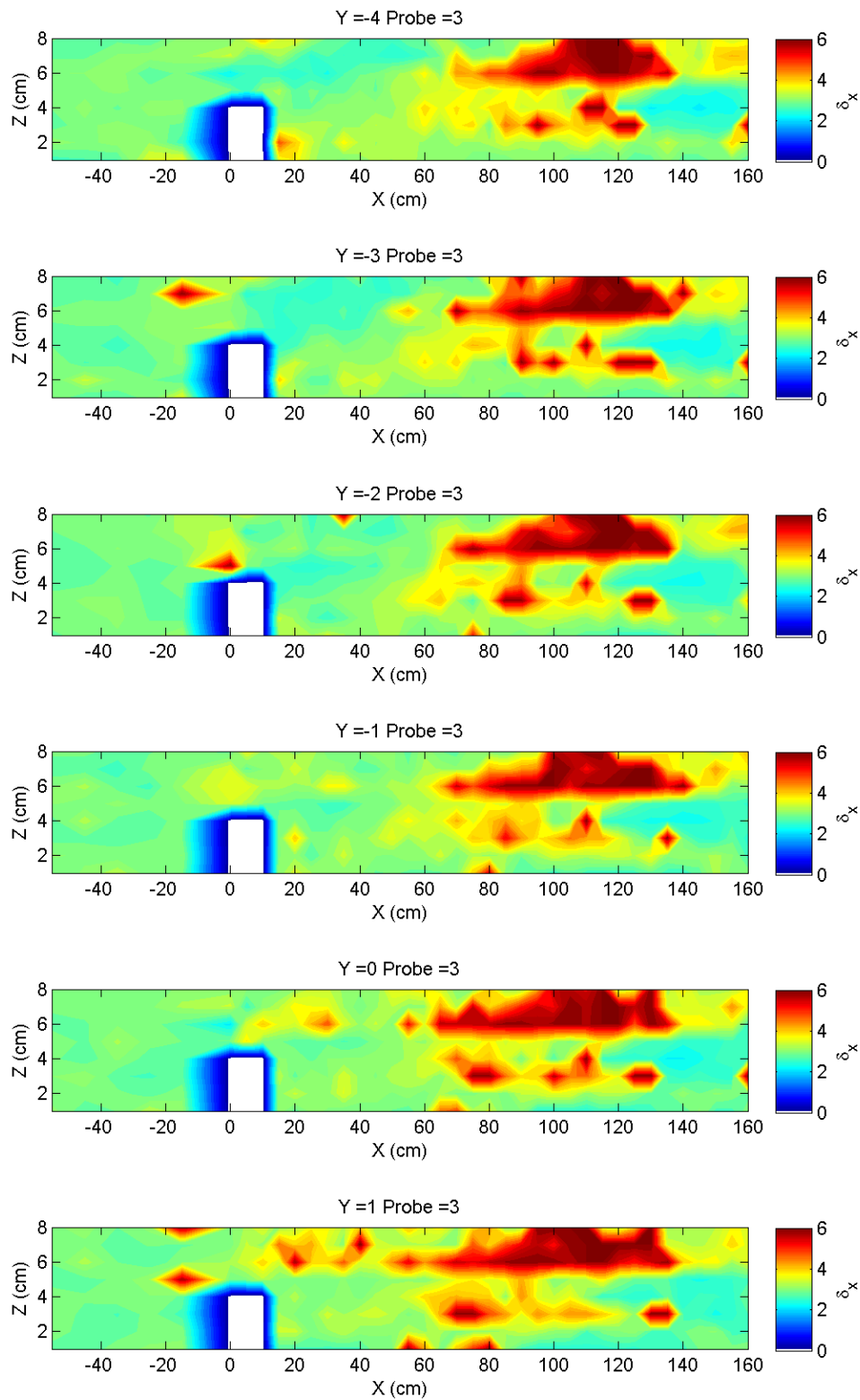


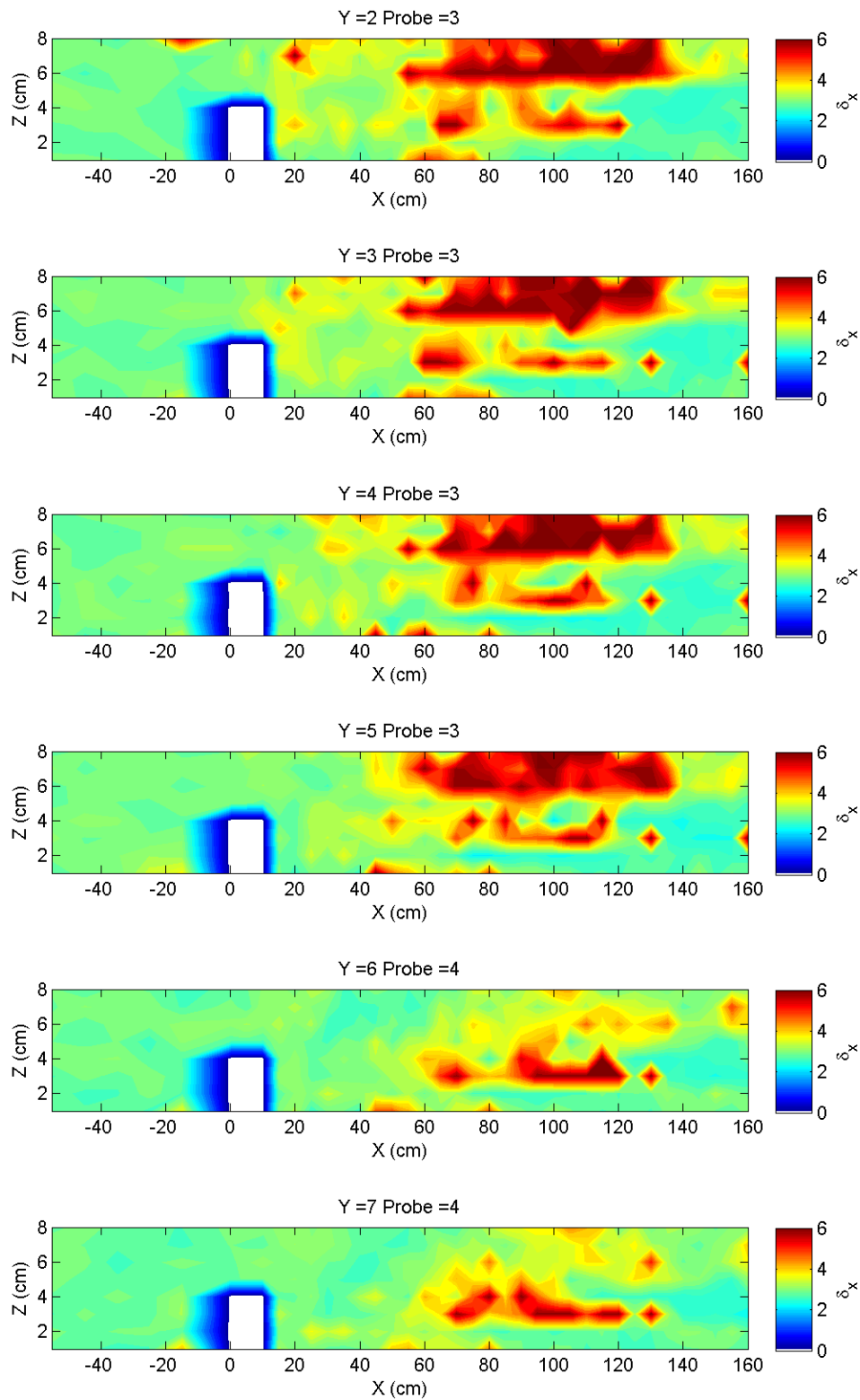


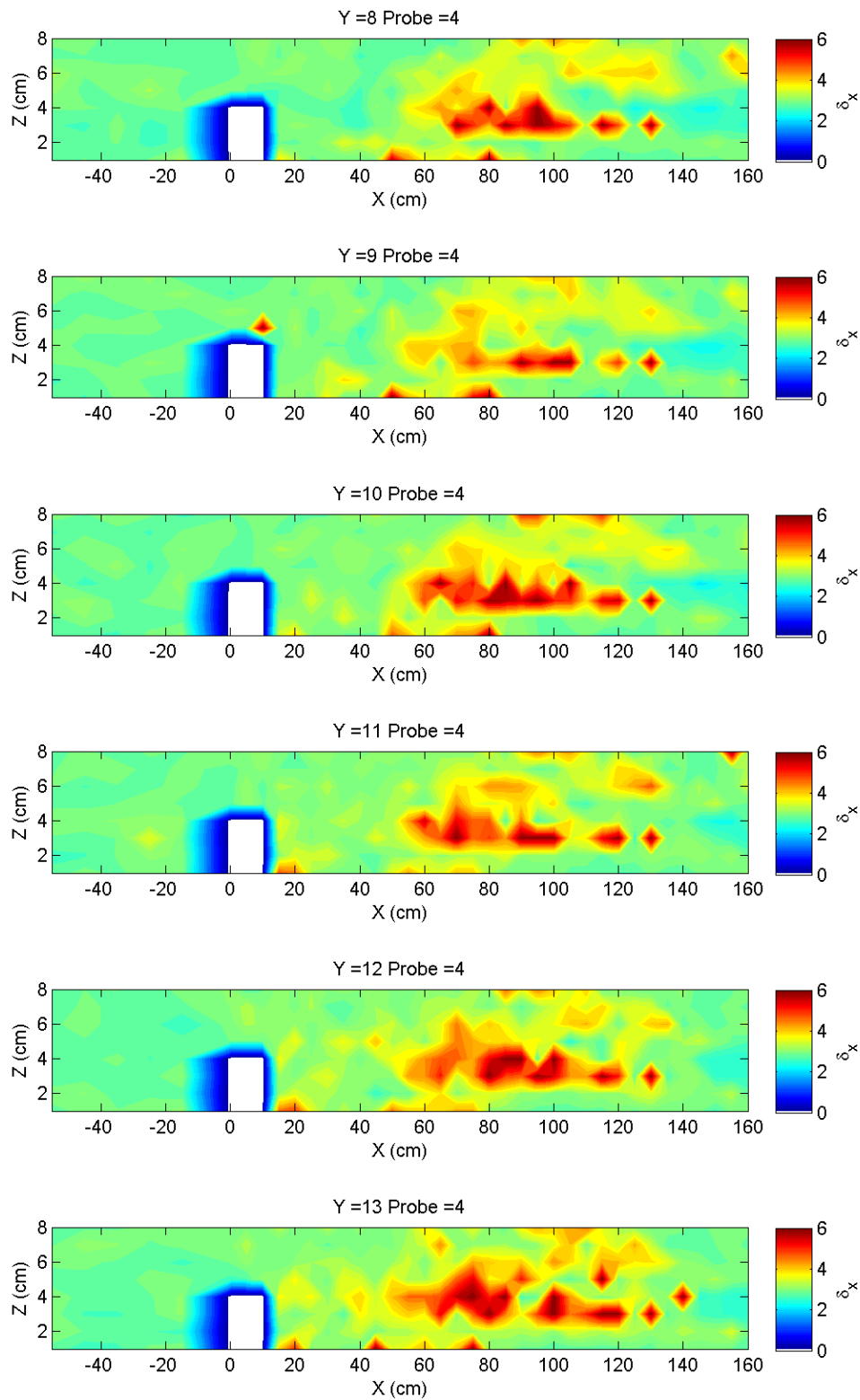


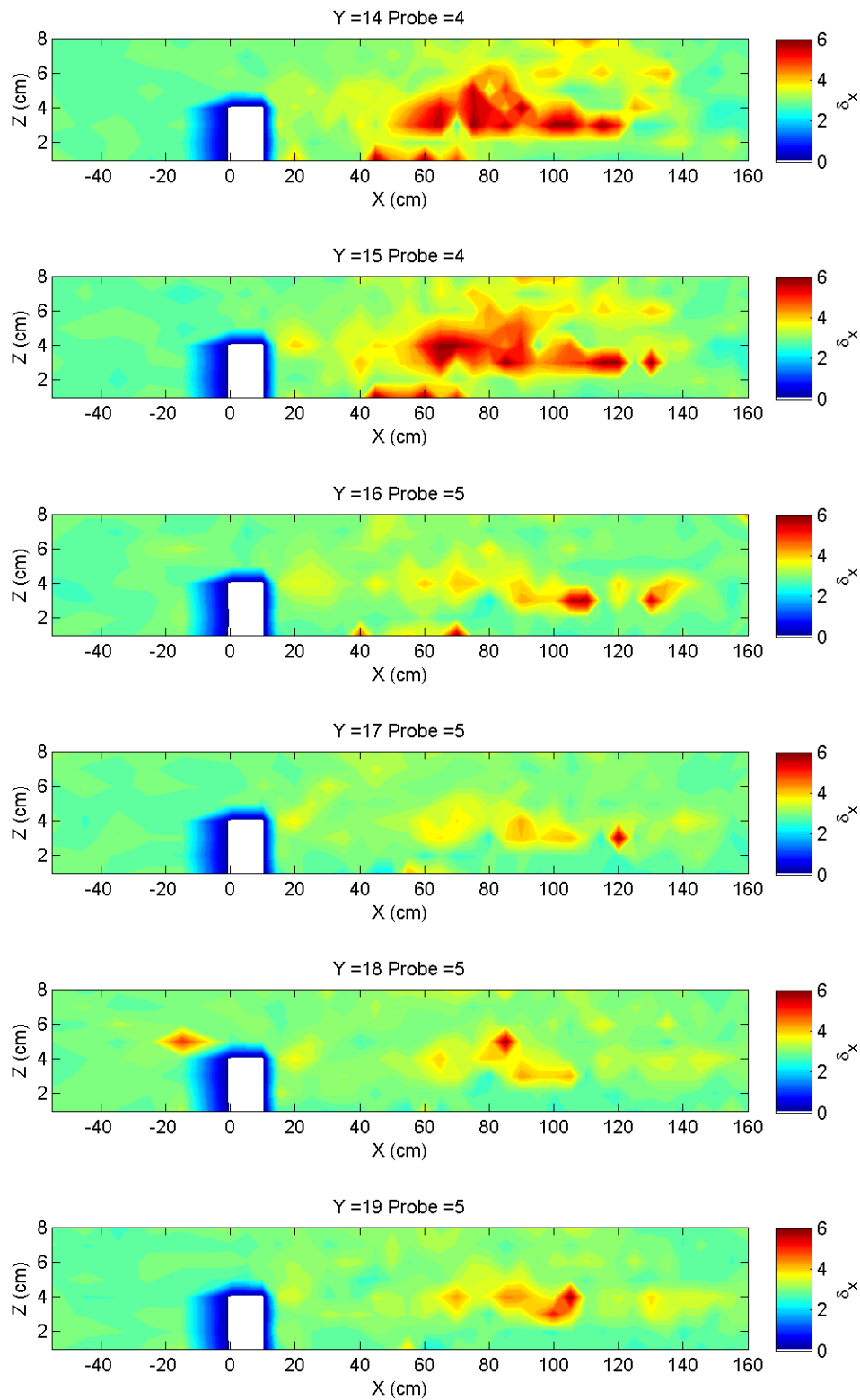


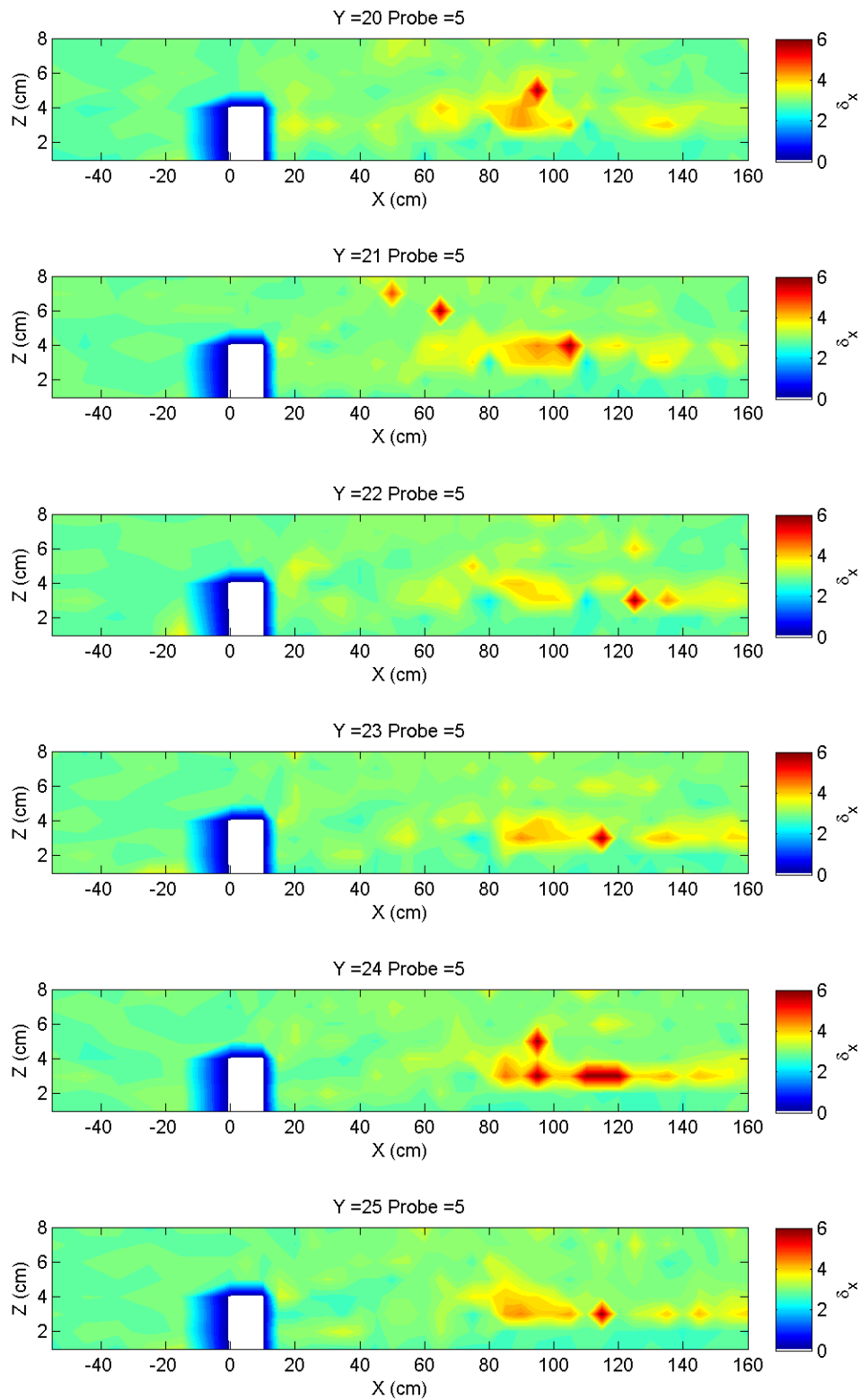


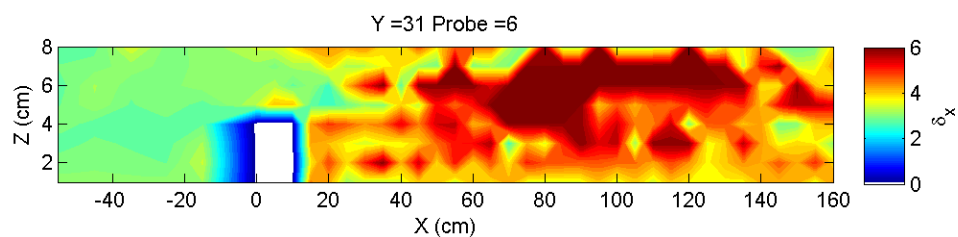
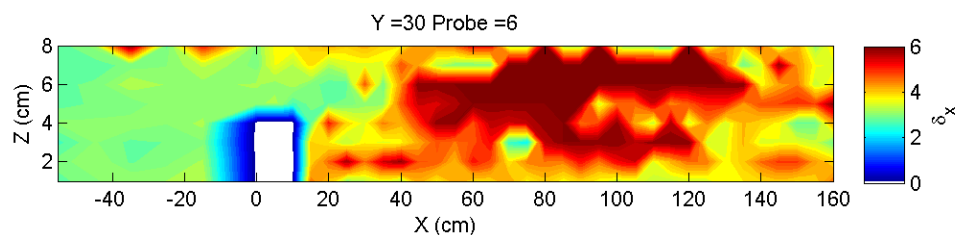
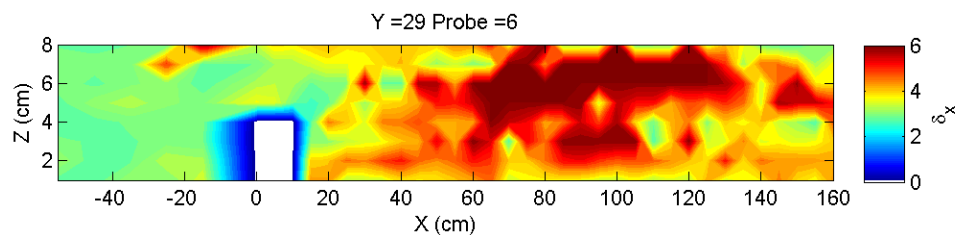
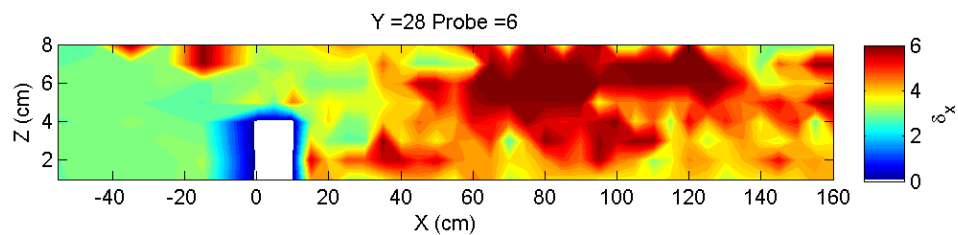
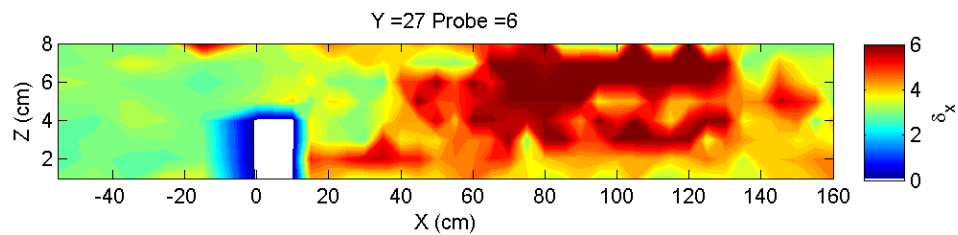
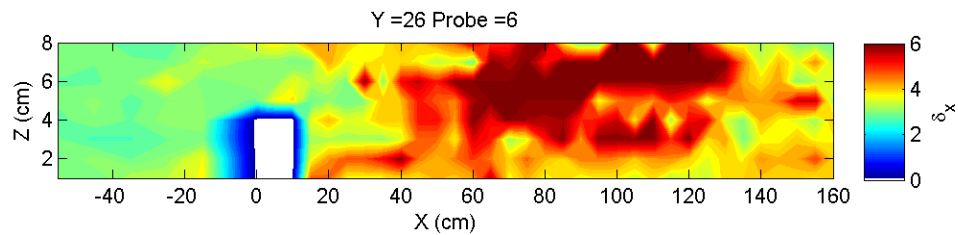


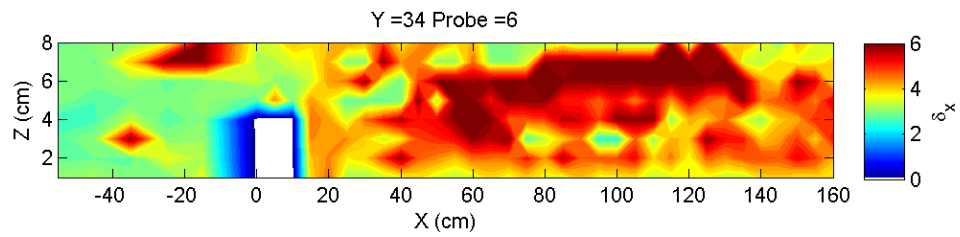
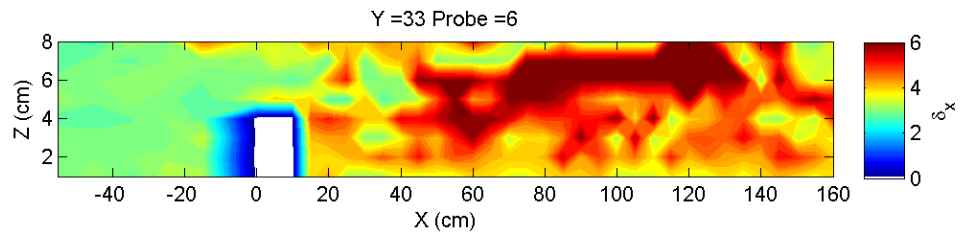
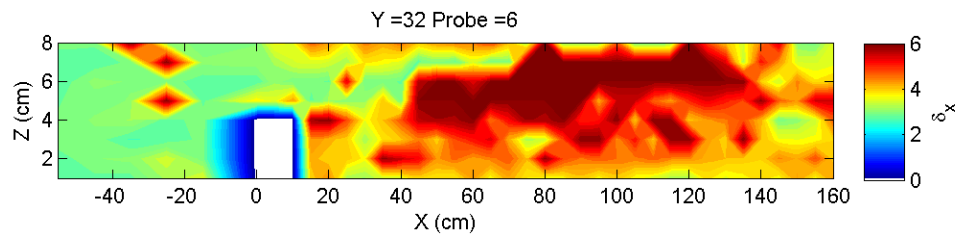




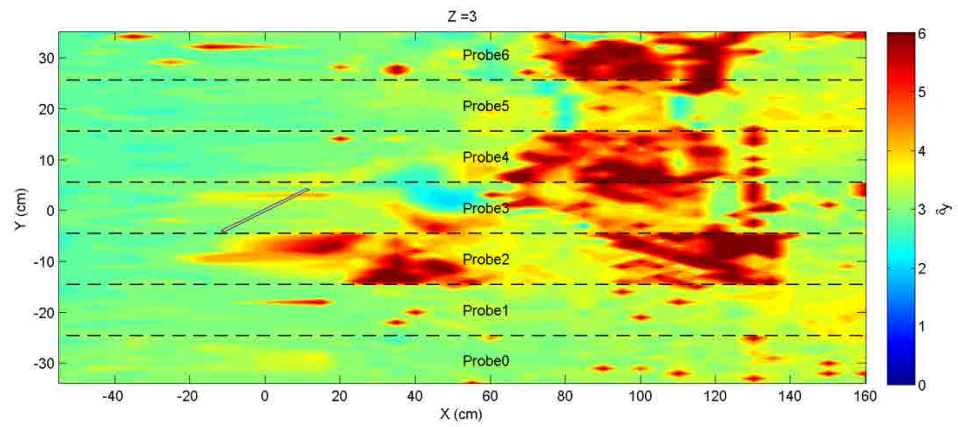
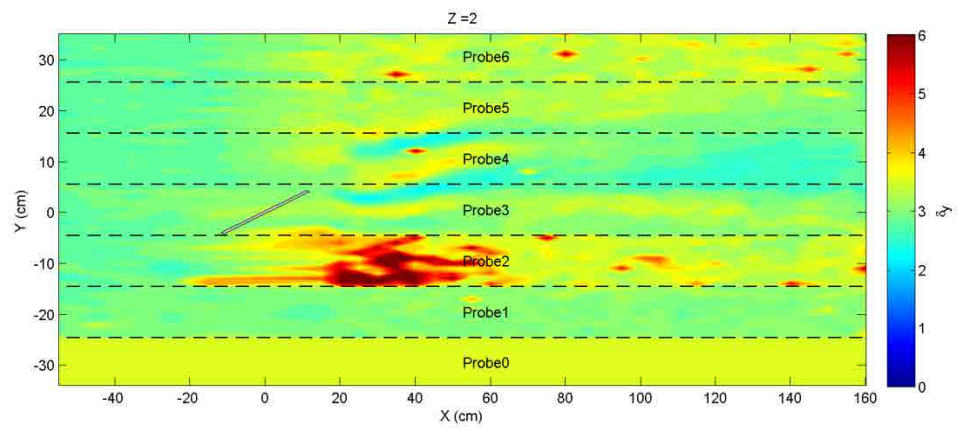
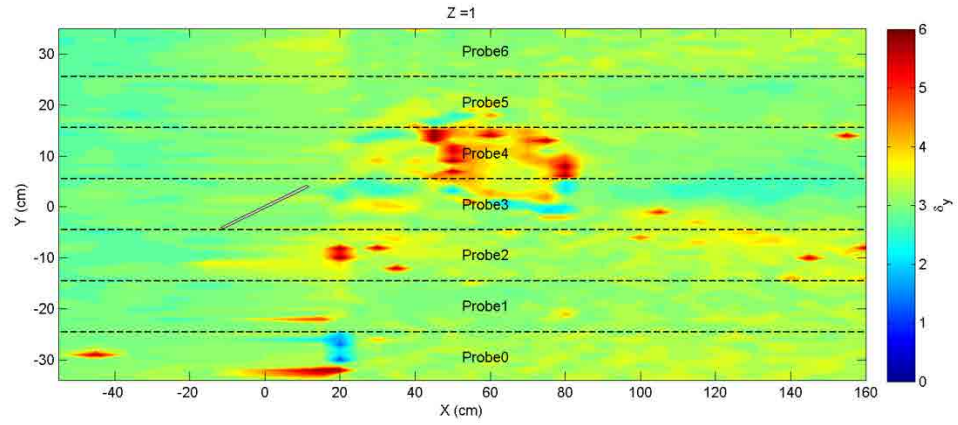




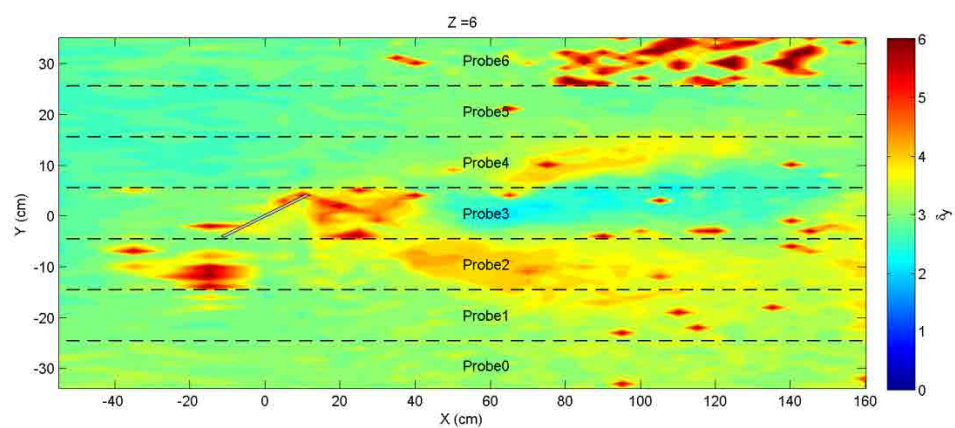
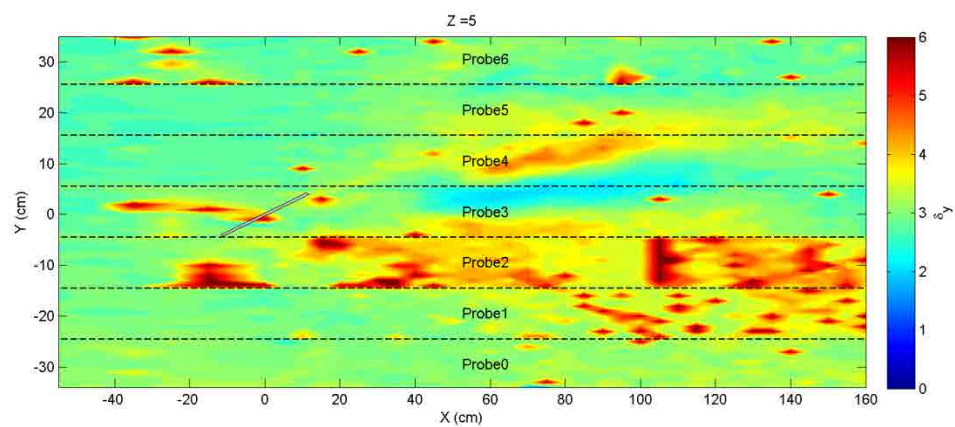
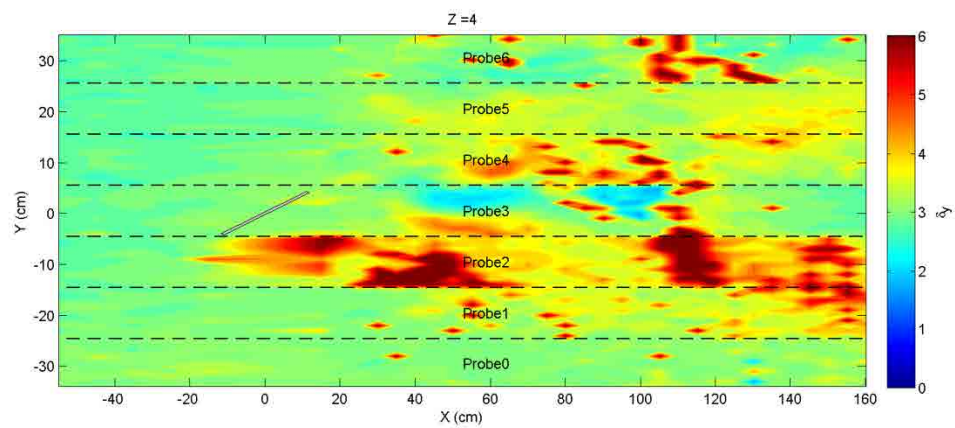


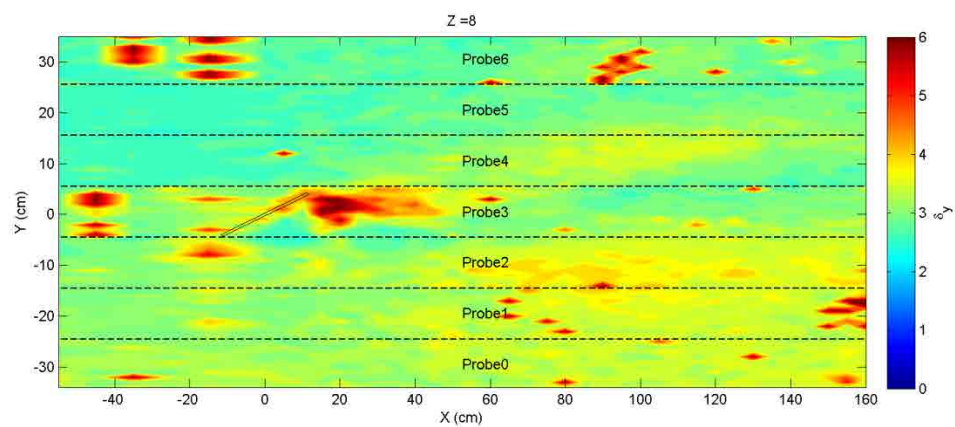
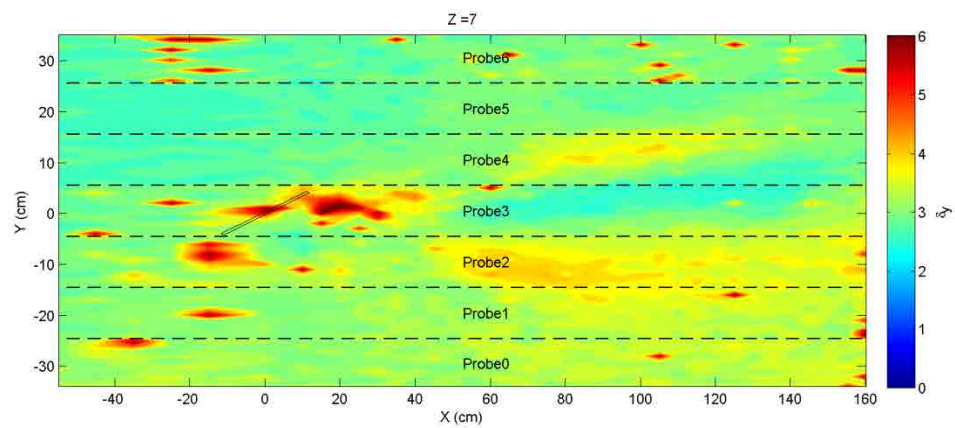


## Kurtosis Factor $\delta_y$ in x and y-Directions

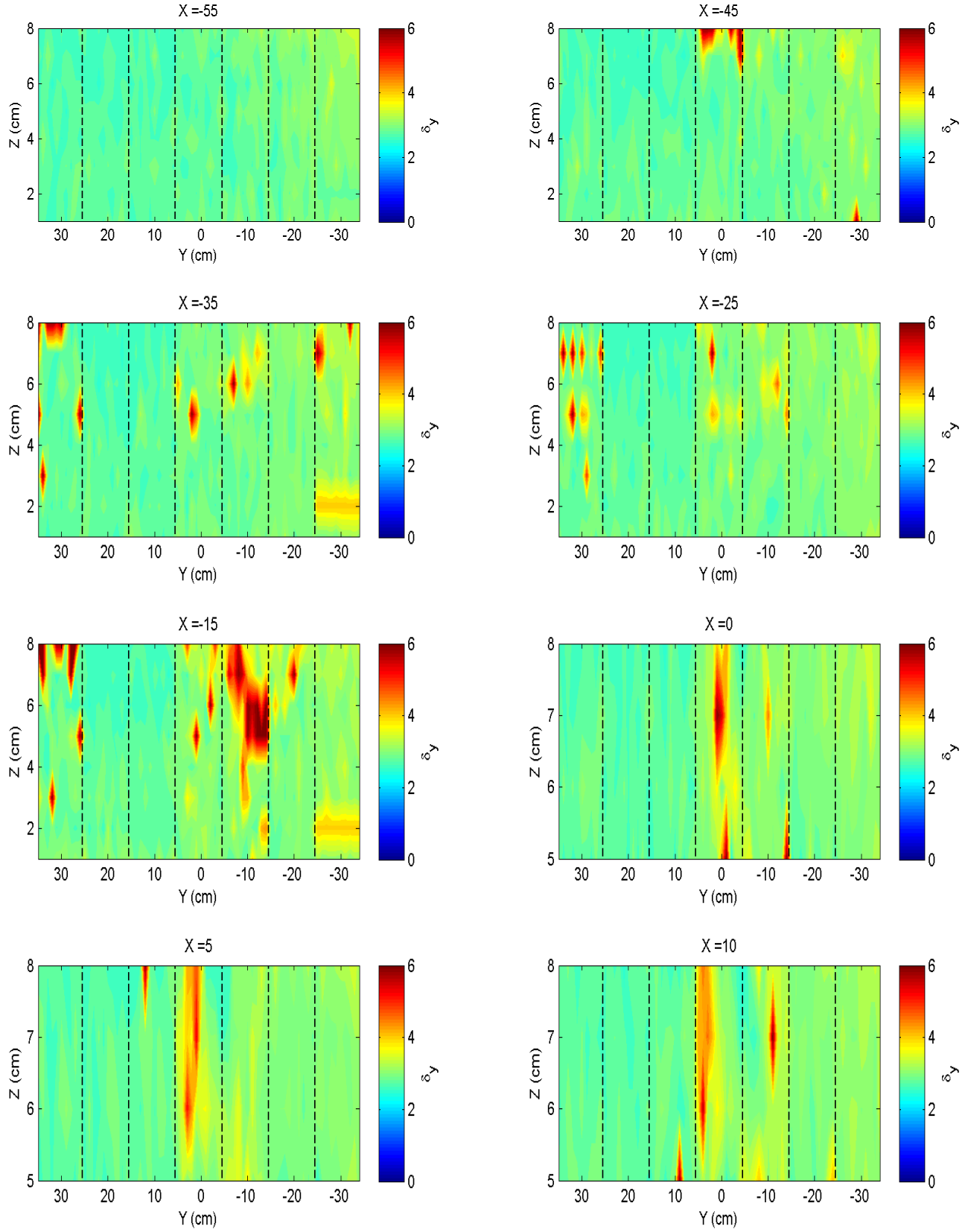


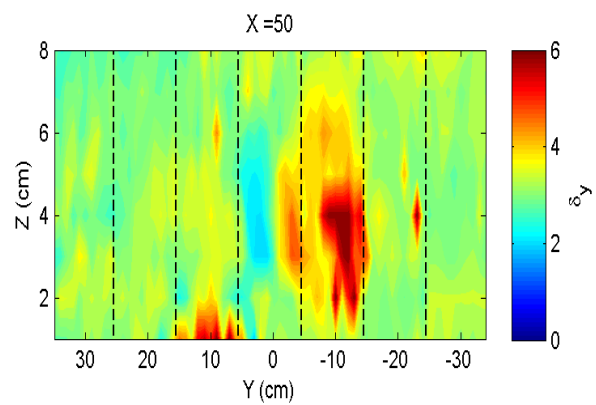
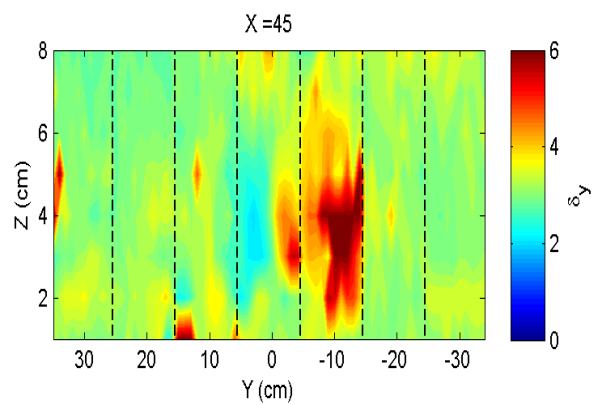
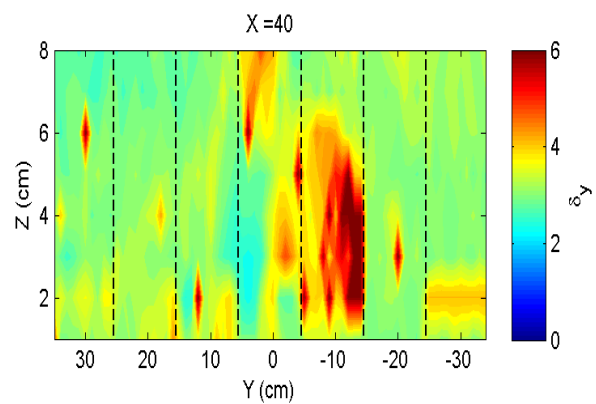
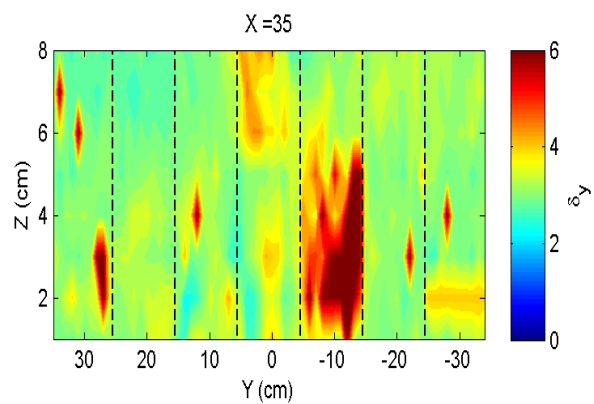
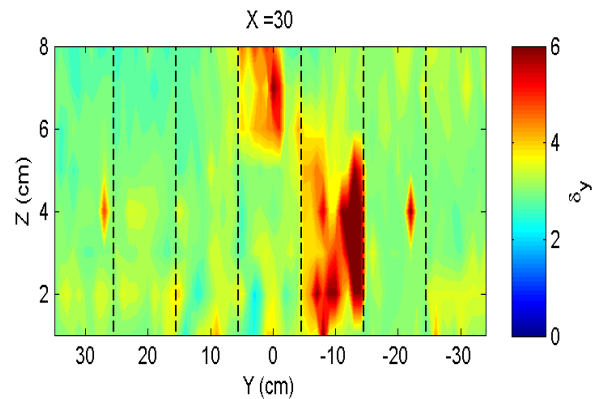
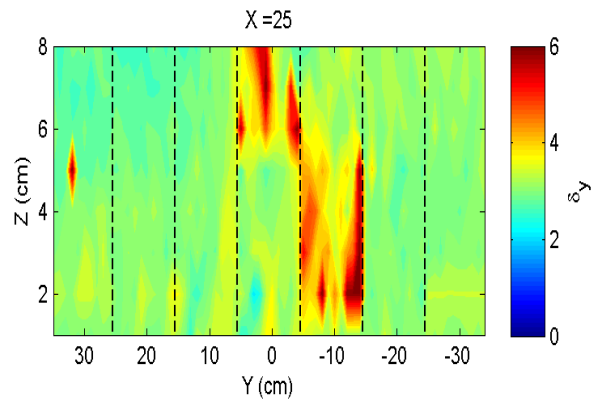
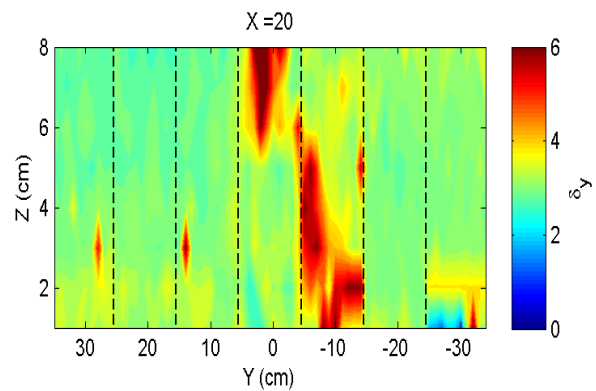
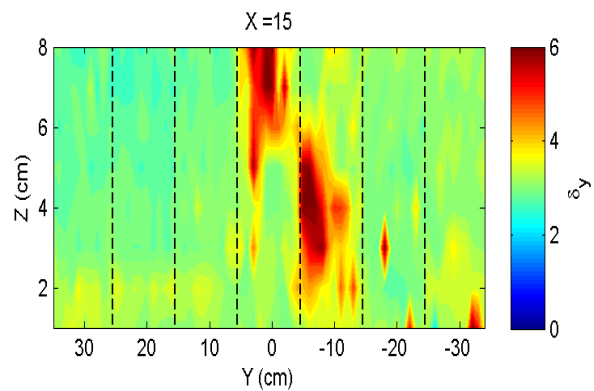


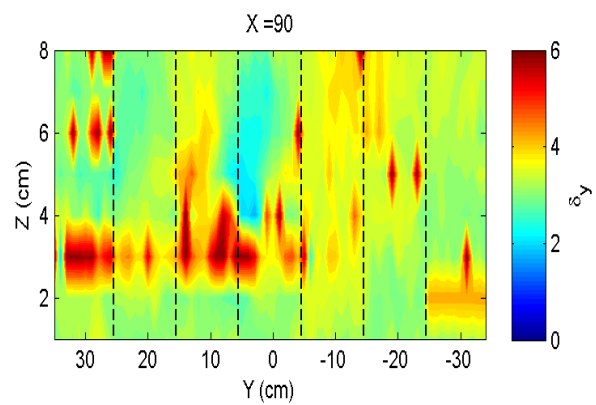
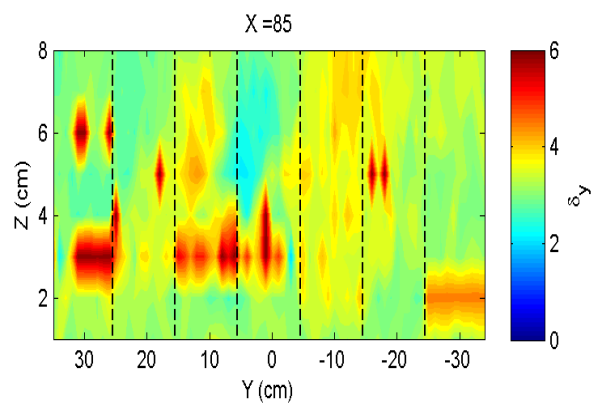
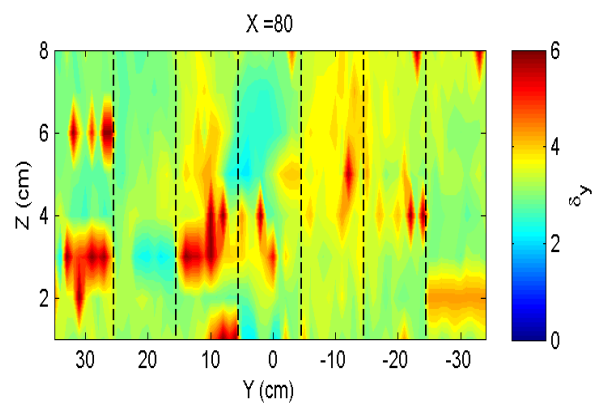
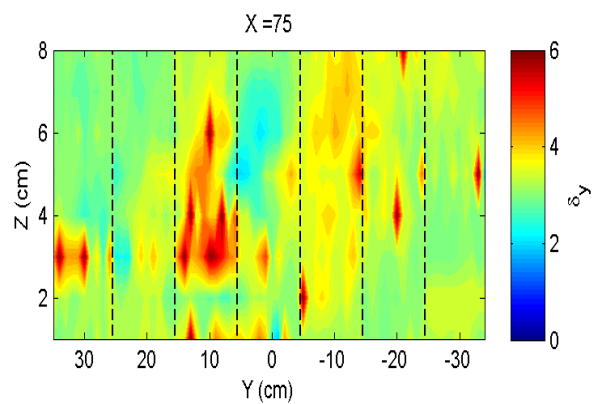
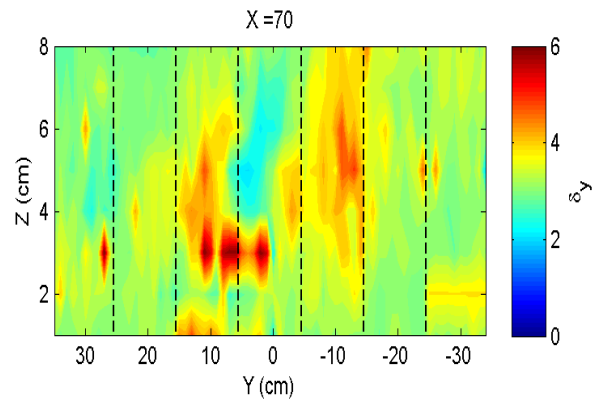
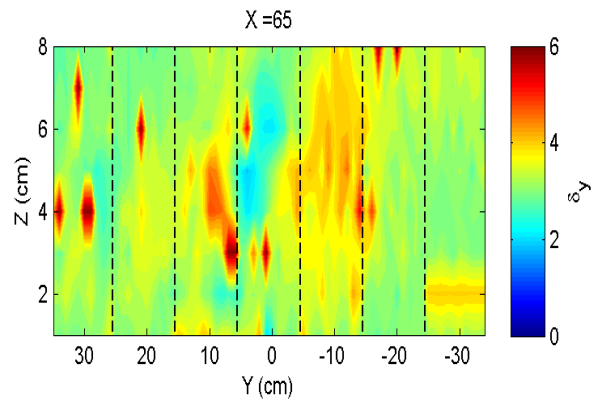
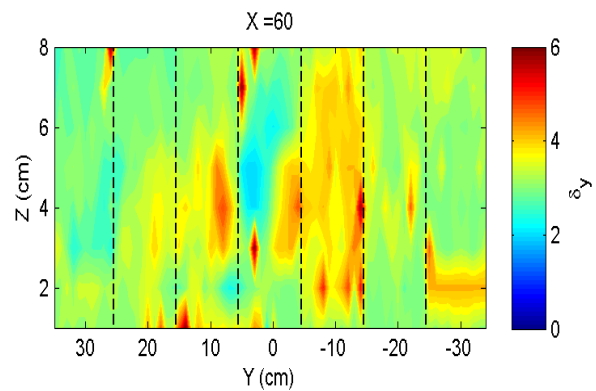
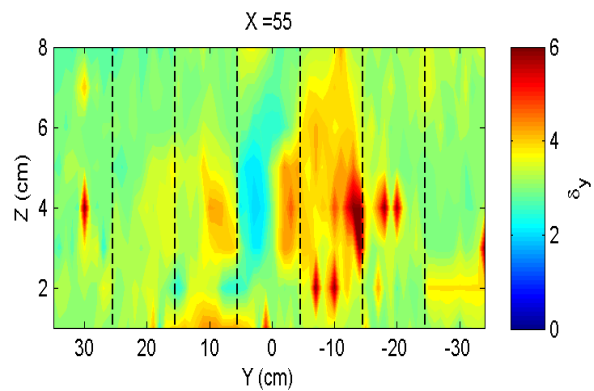




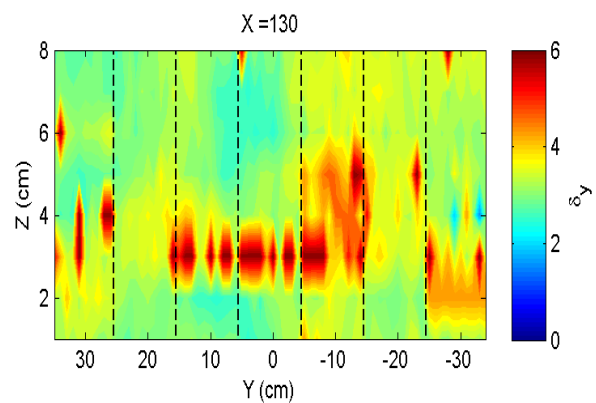
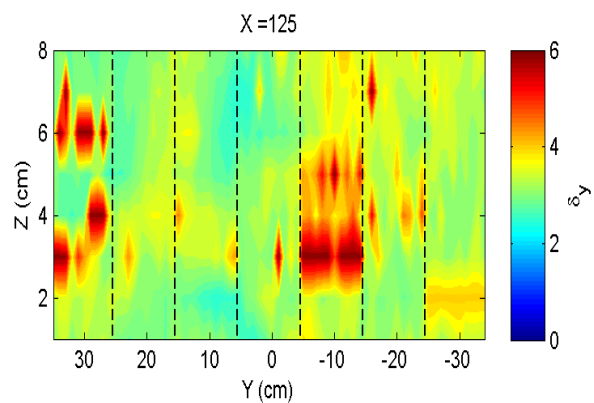
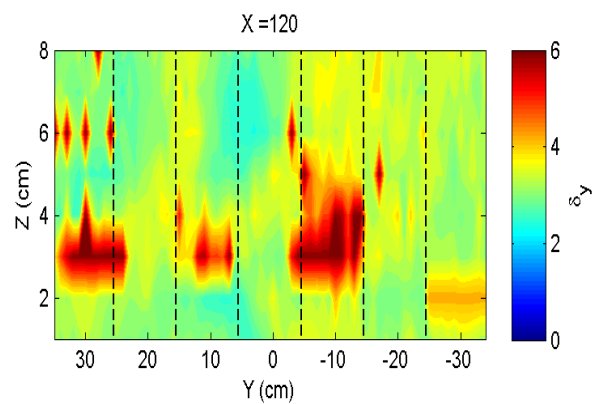
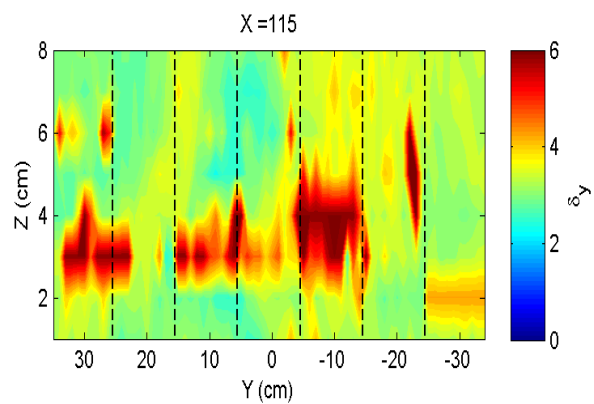
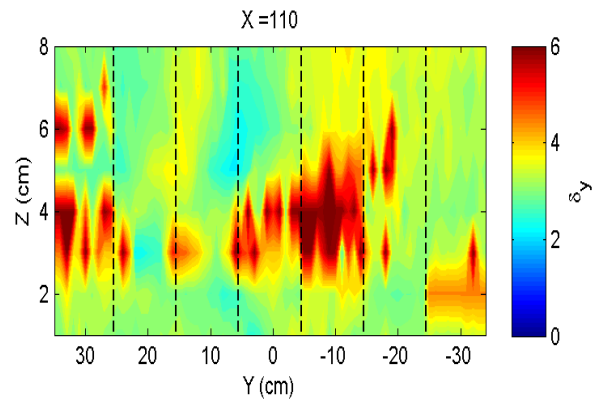
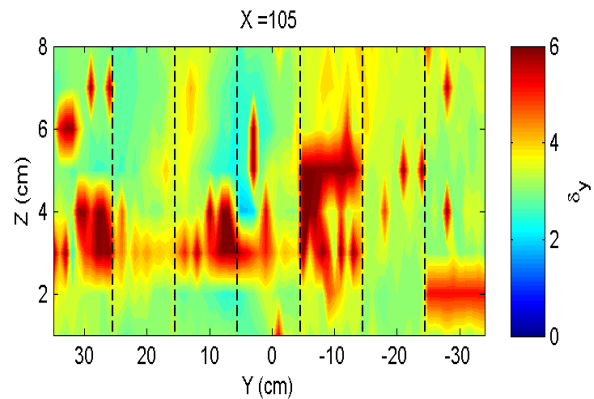
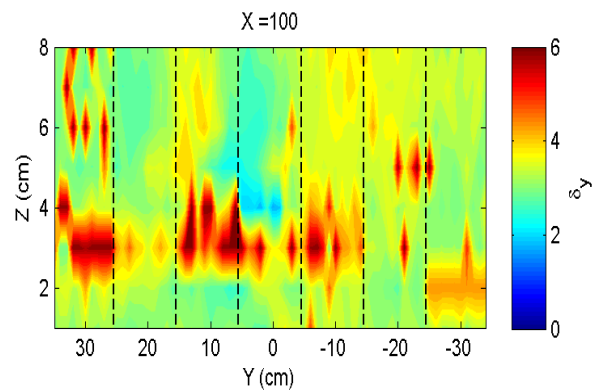
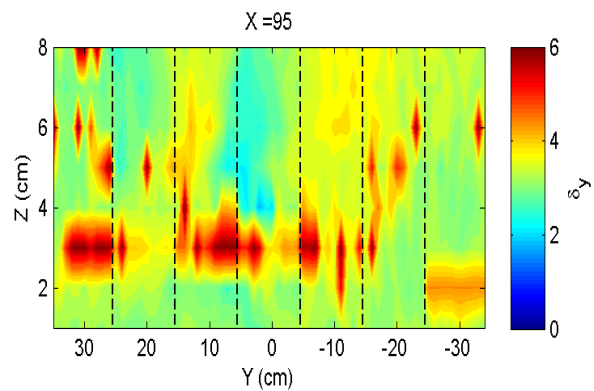
## Kurtosis Factor $\delta_y$ in y and z-Directions

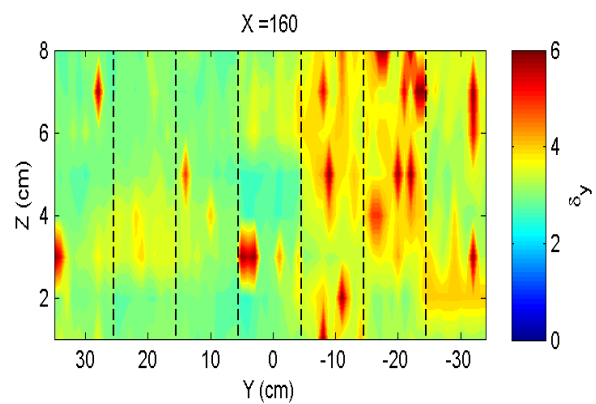
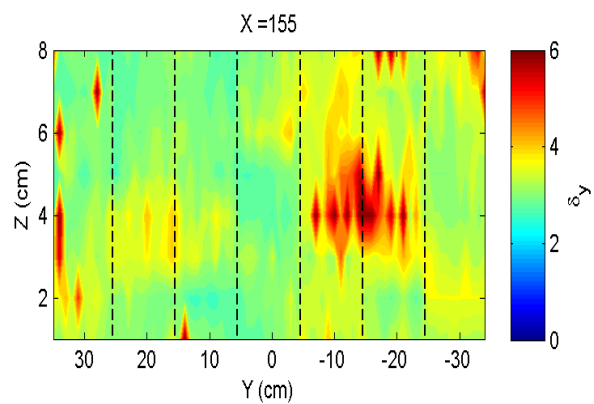
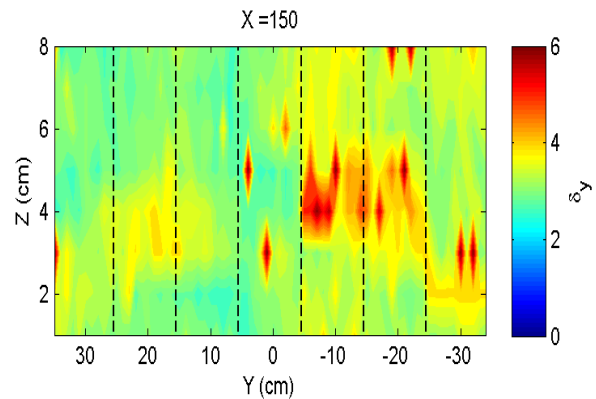
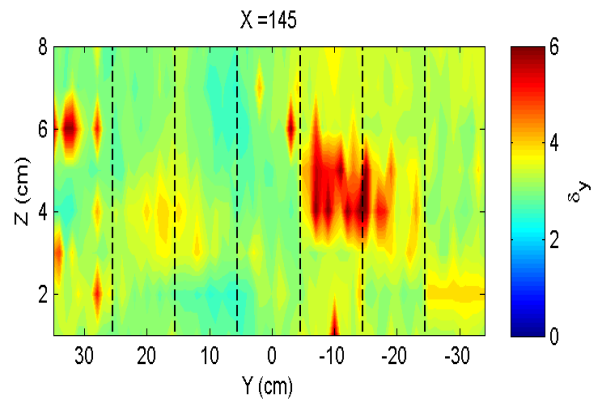
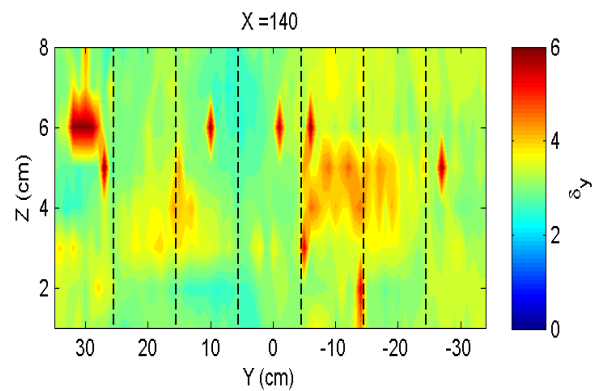
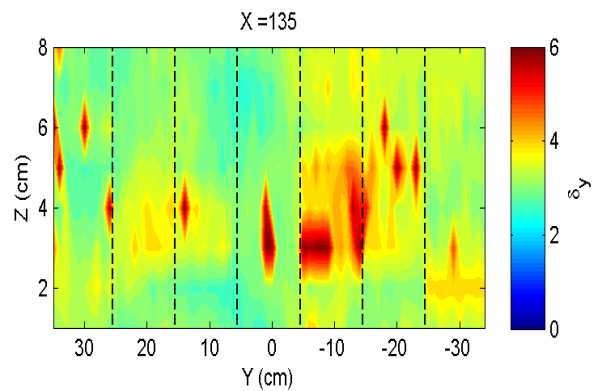




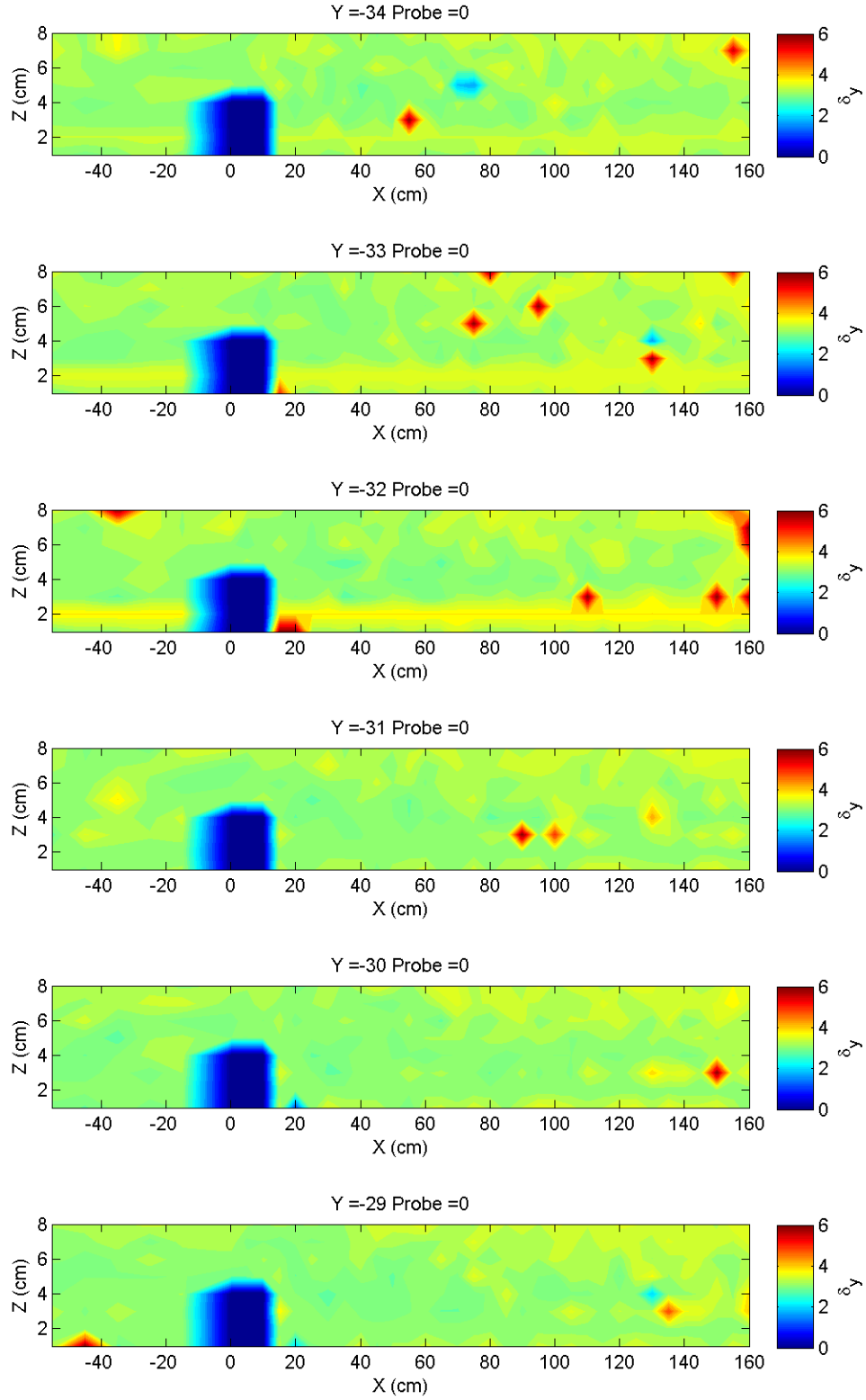




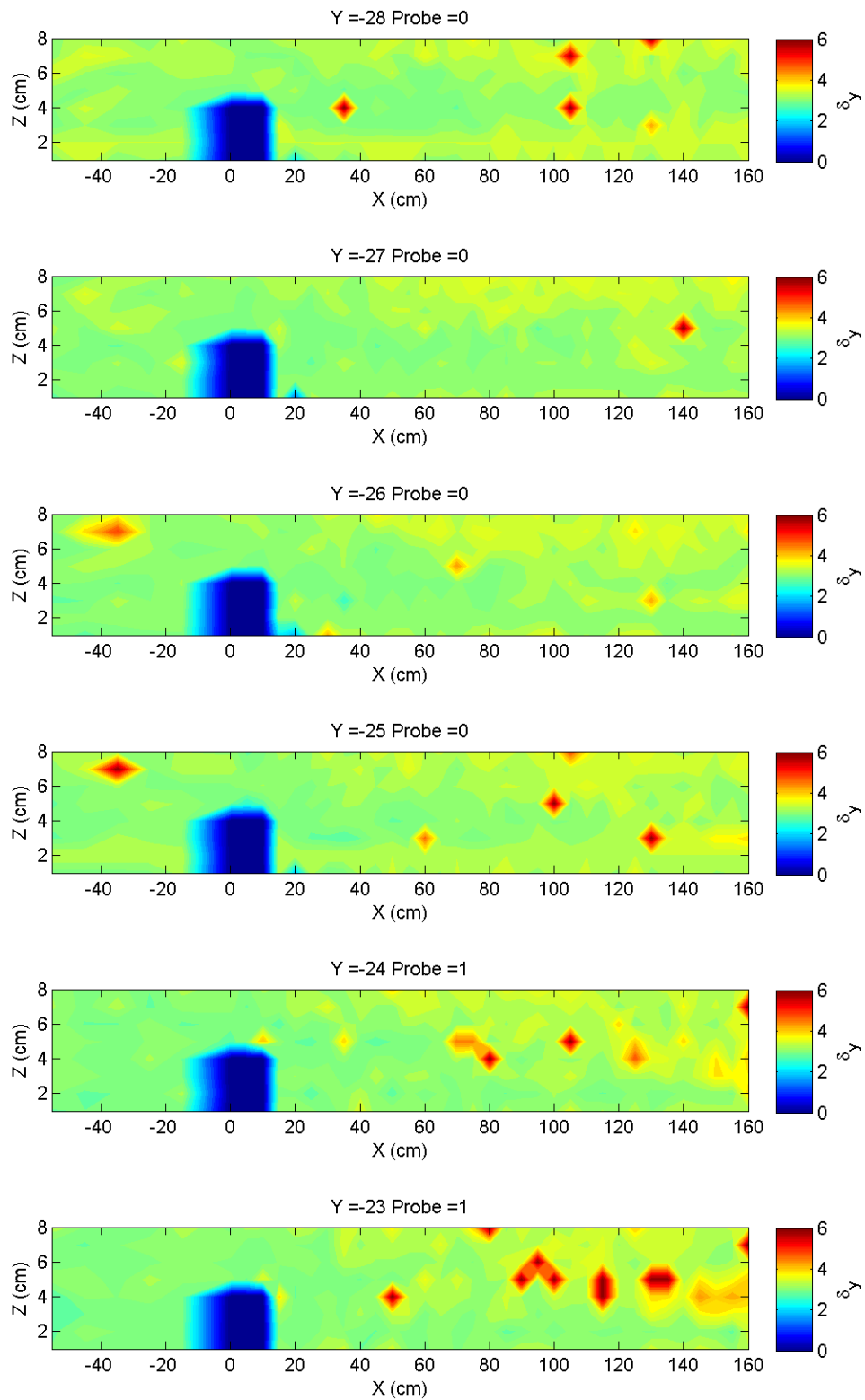


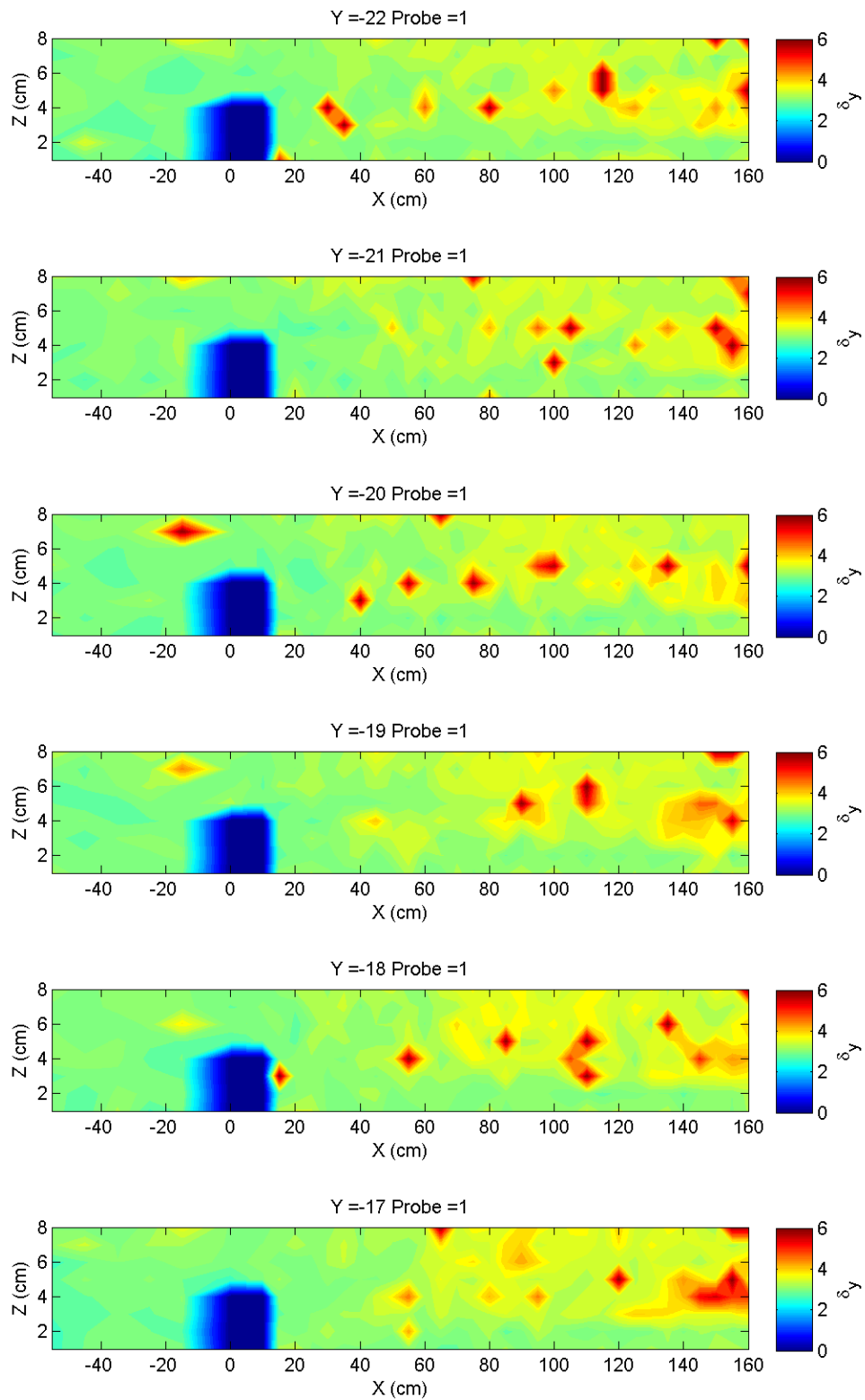


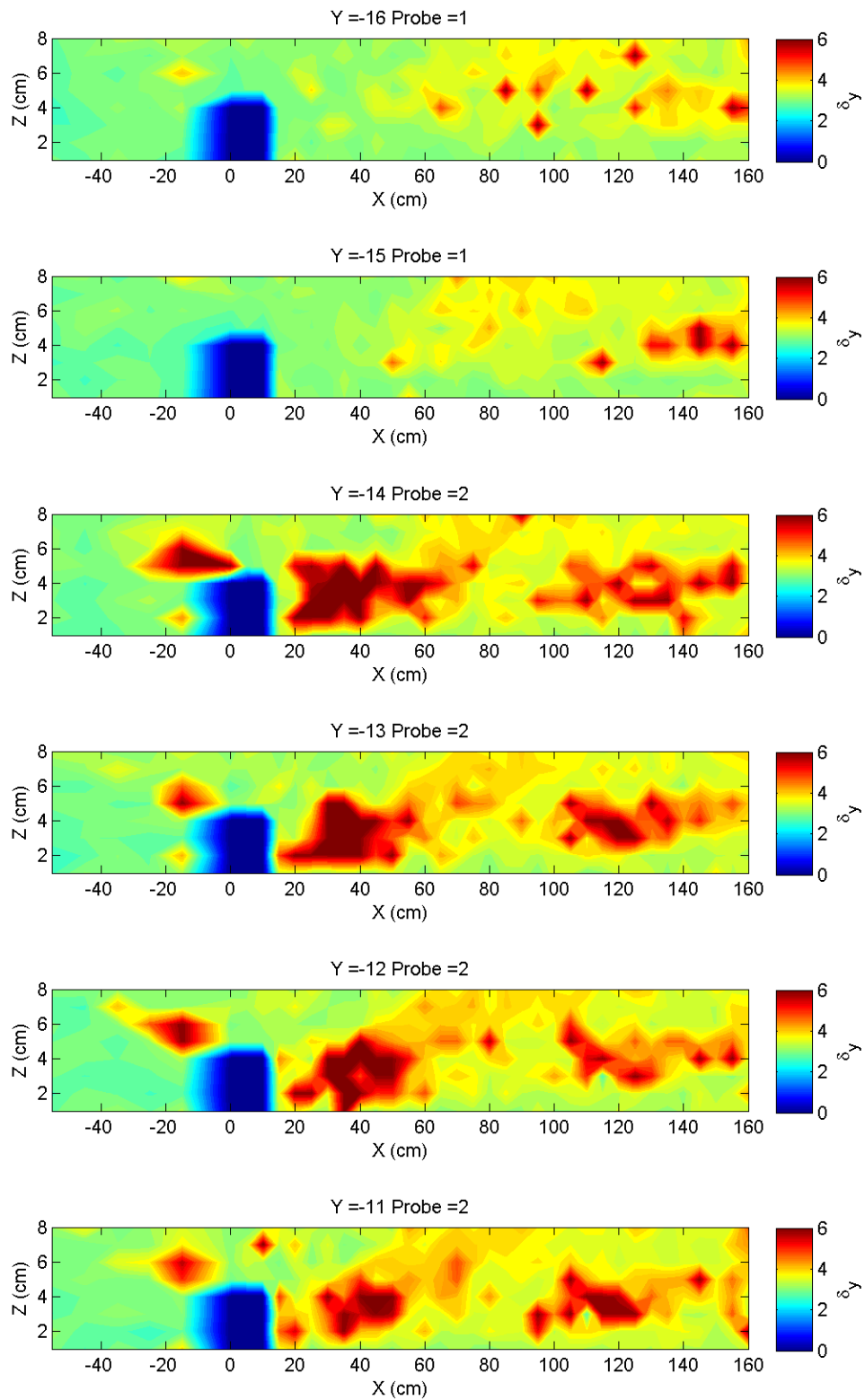
## Kurtosis Factor $\delta_y$ in x and z-Directions

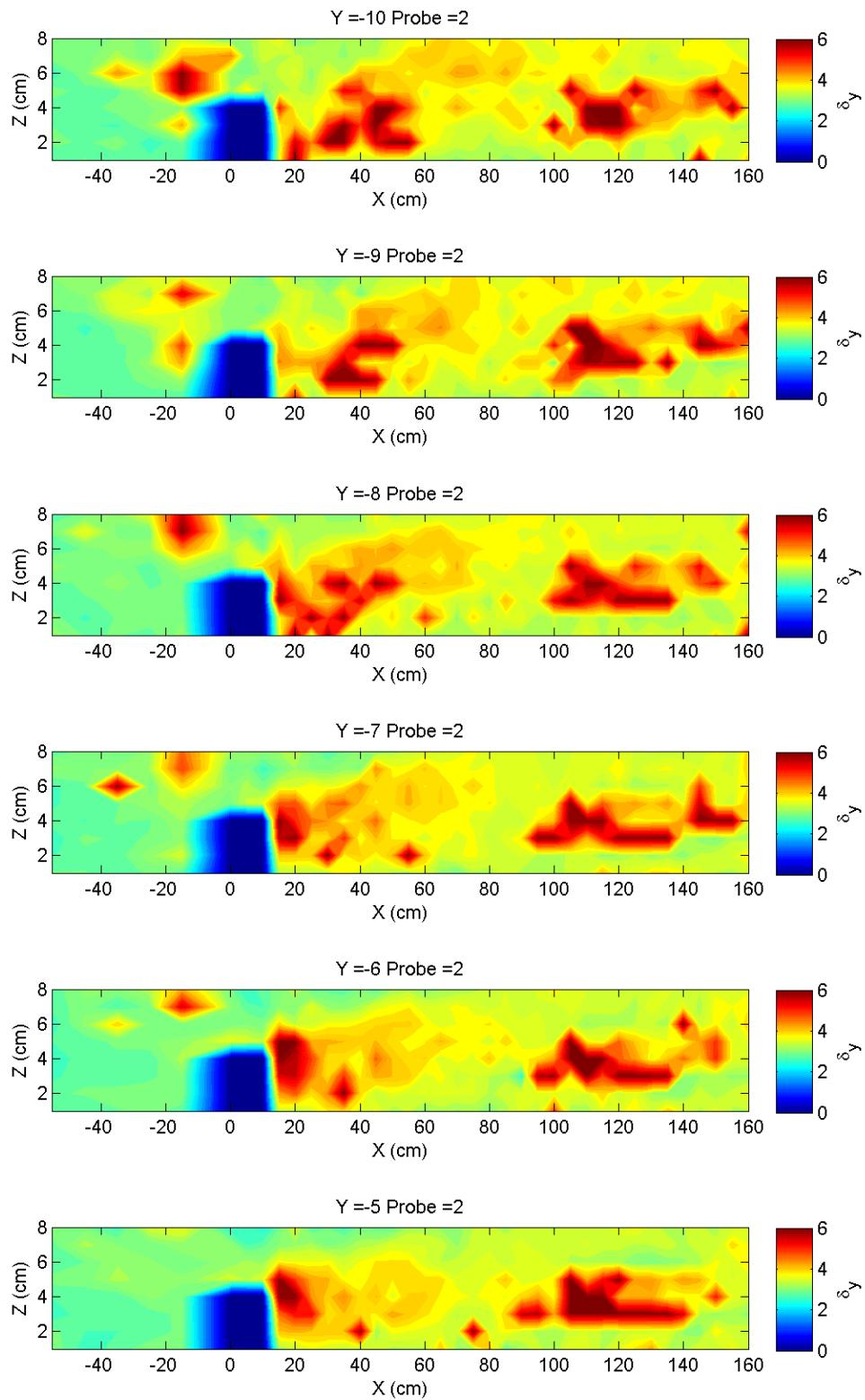


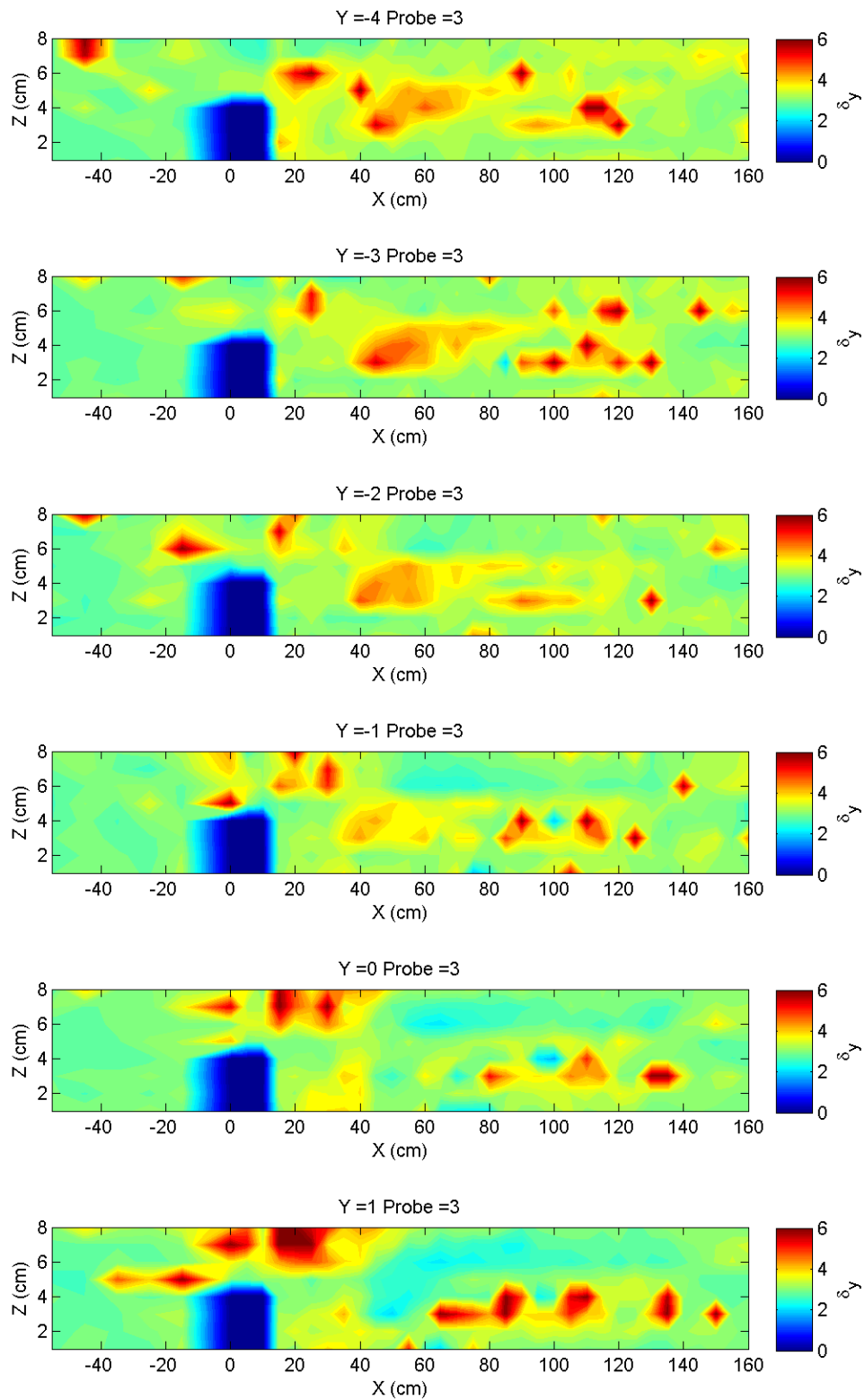


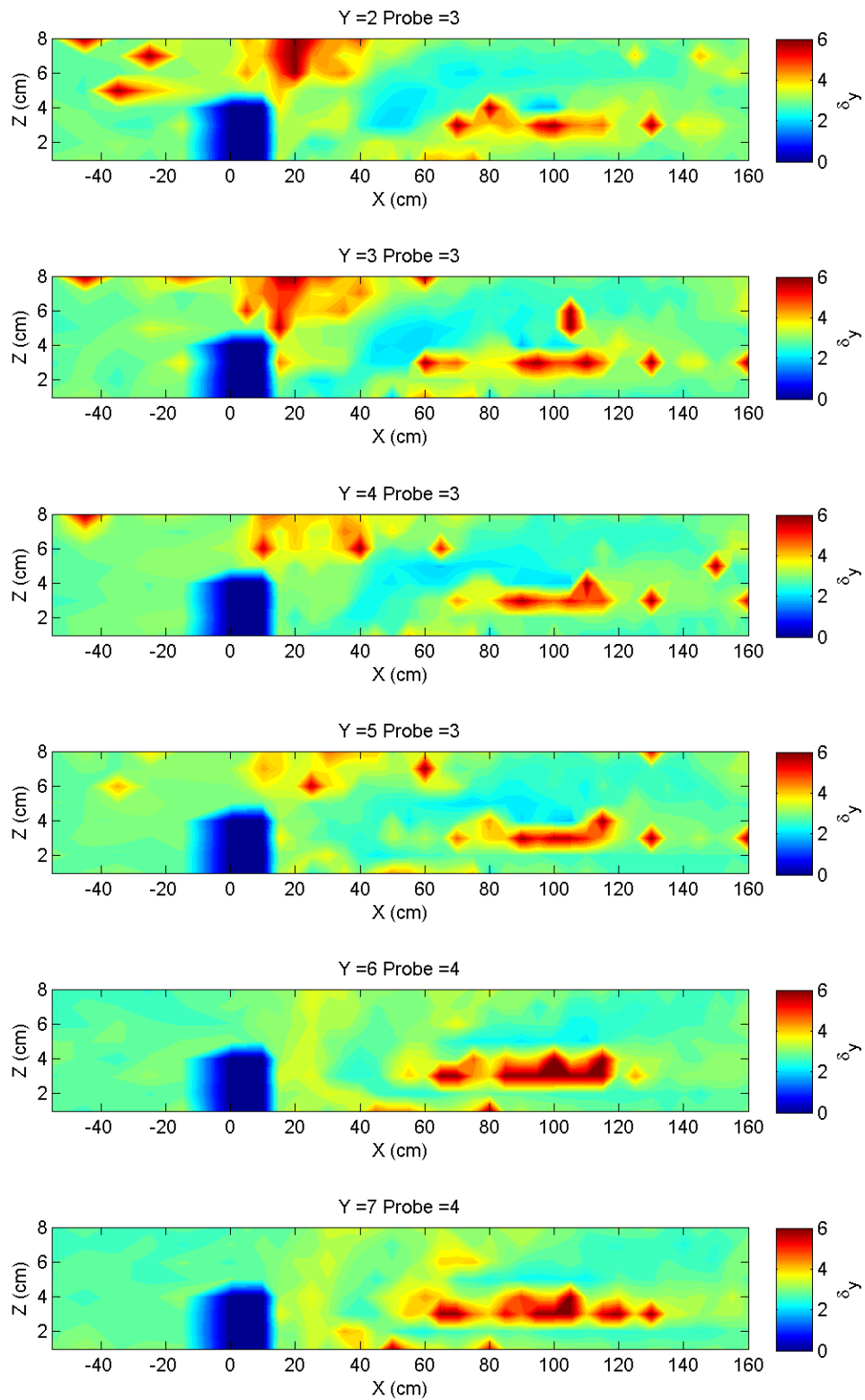


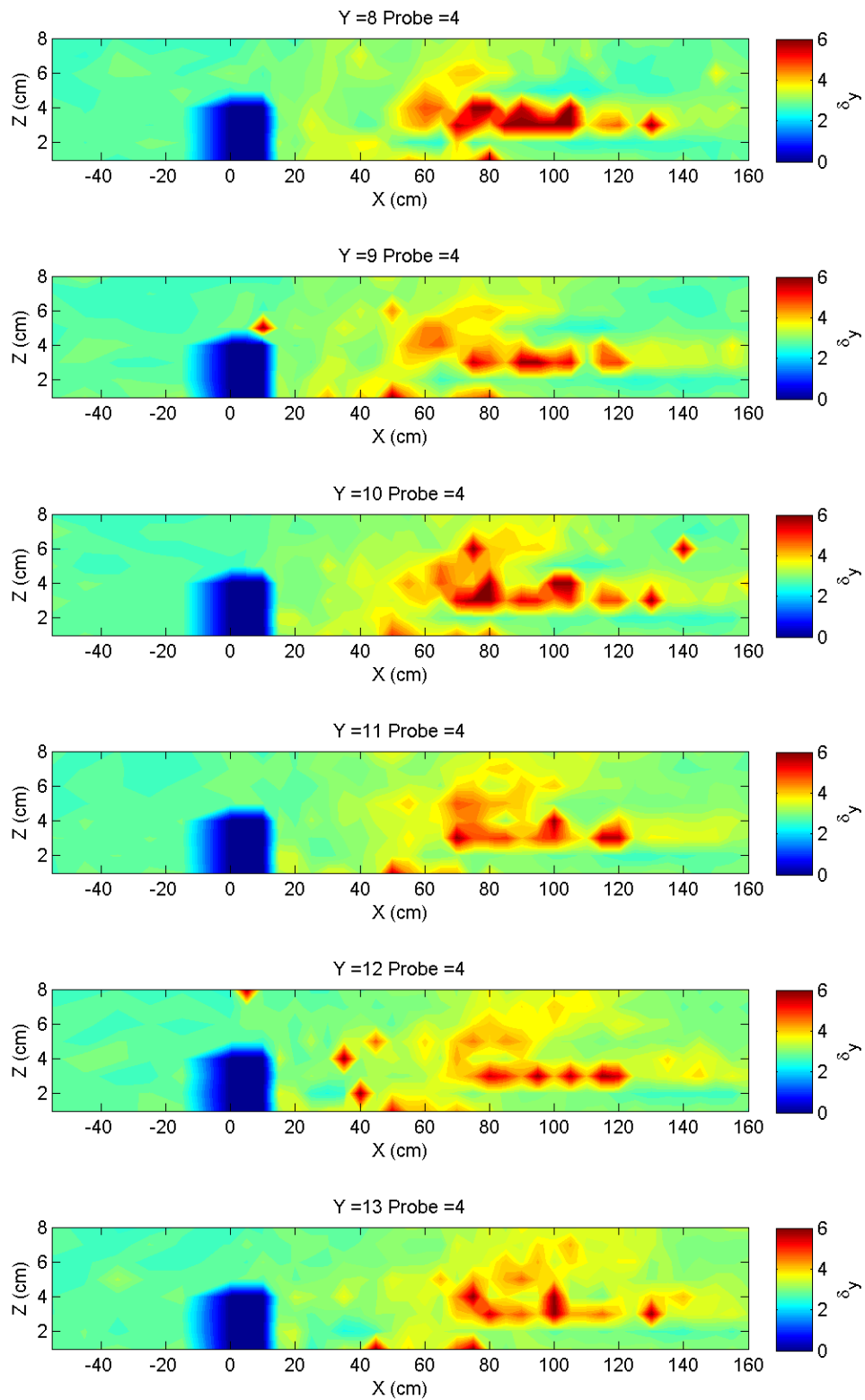


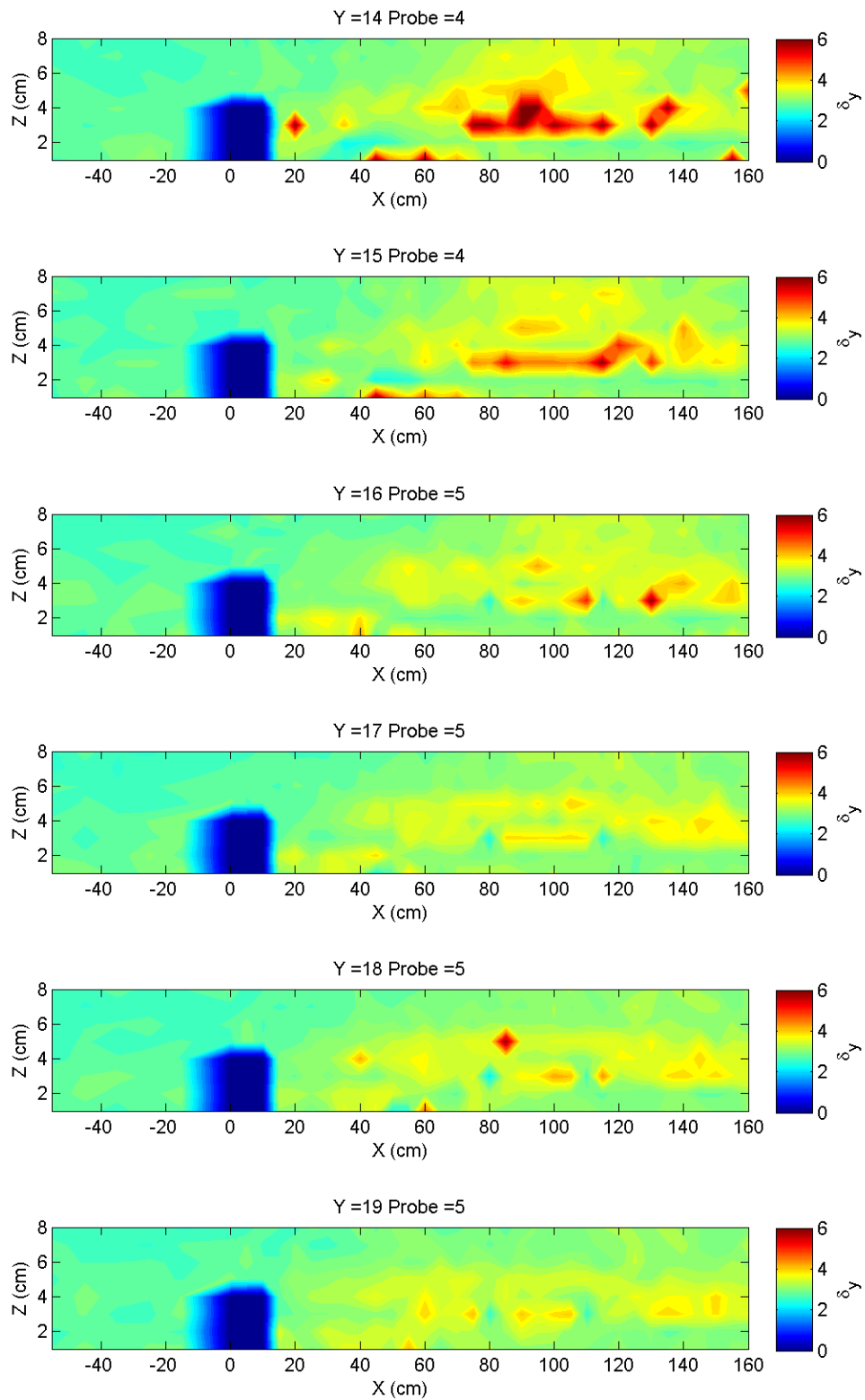




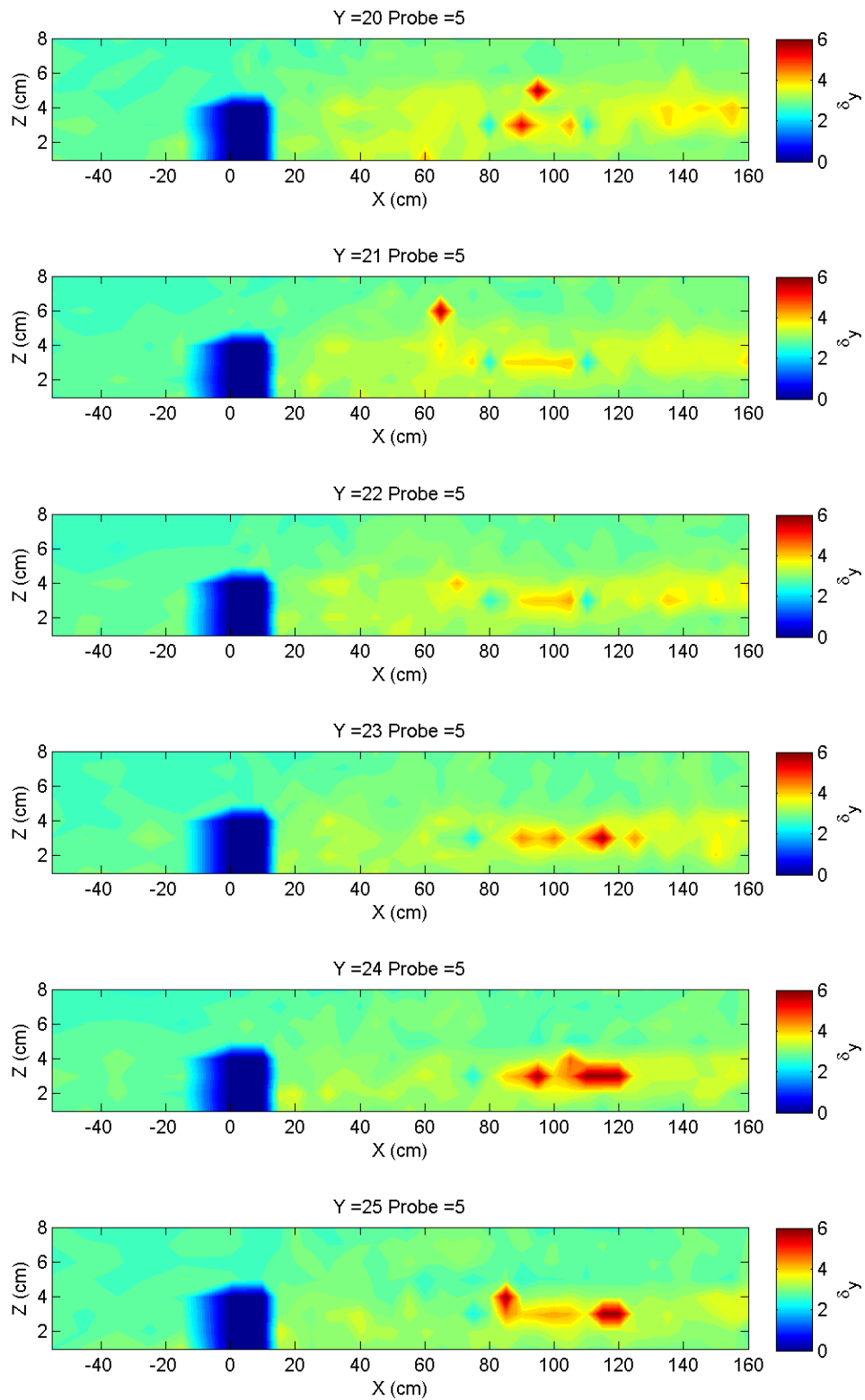


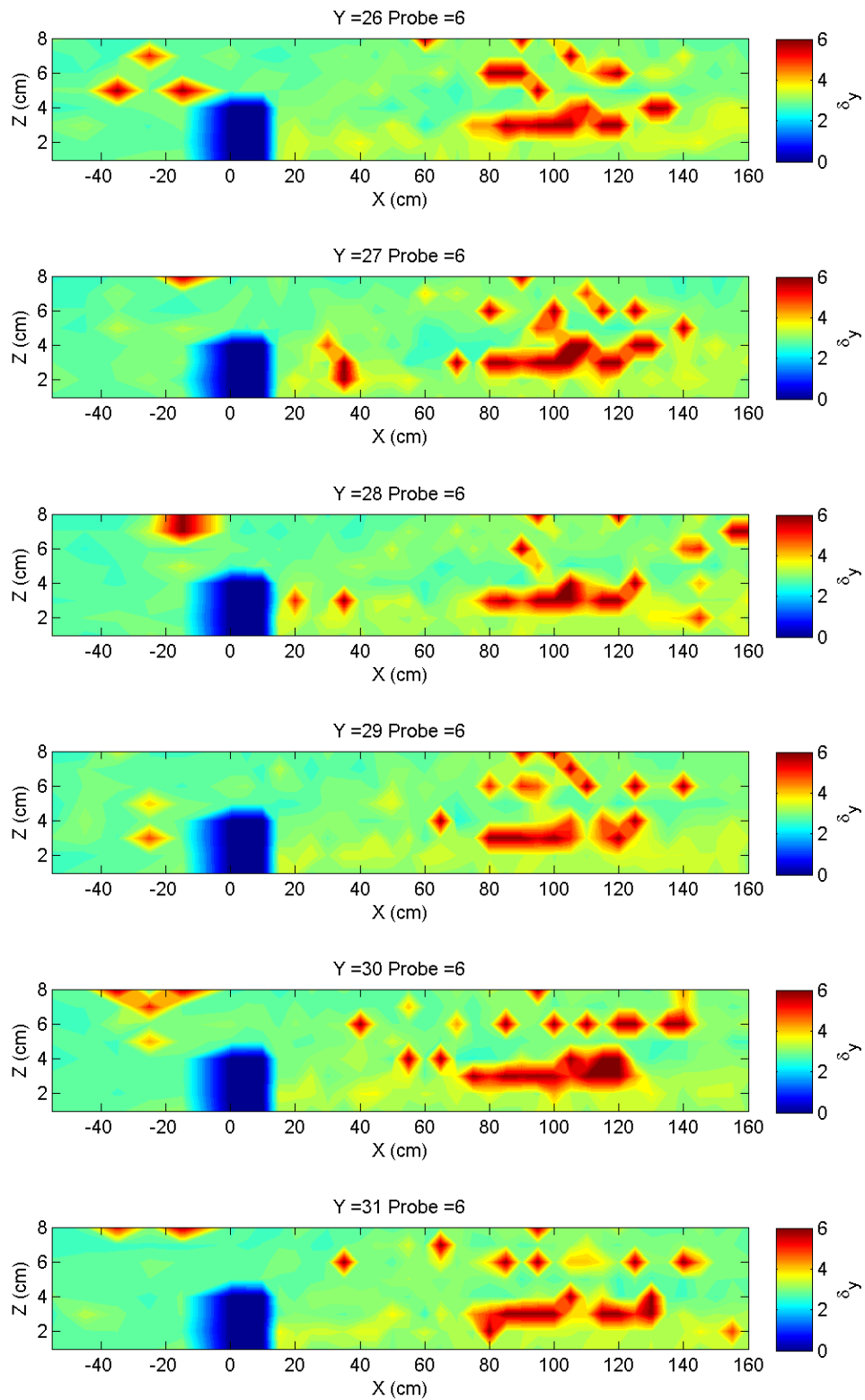


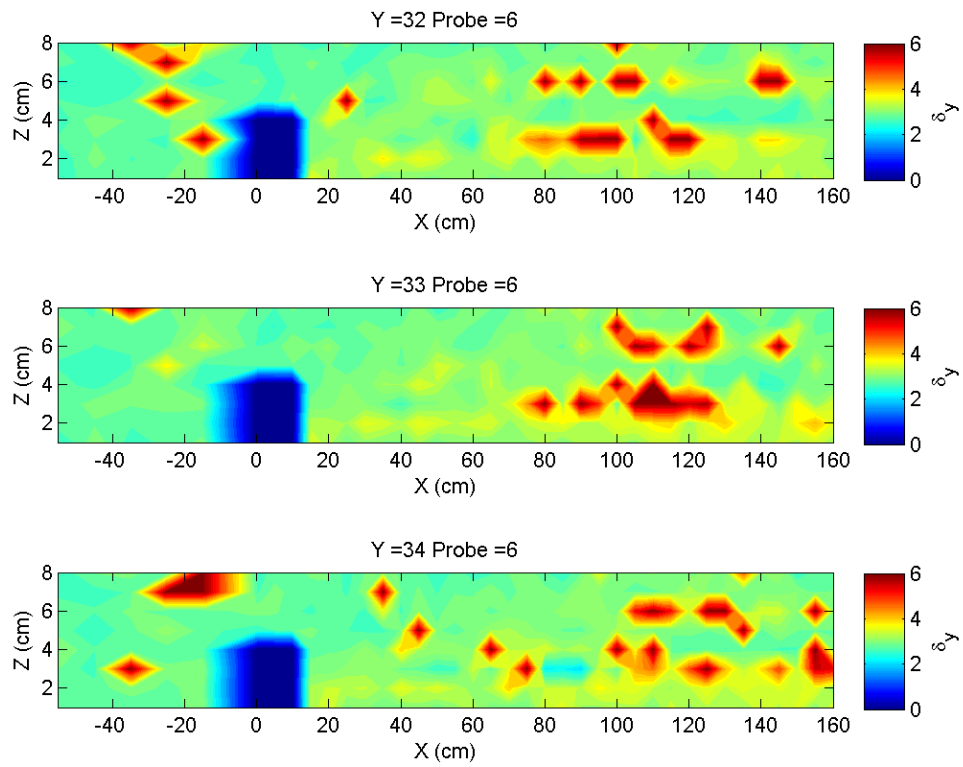




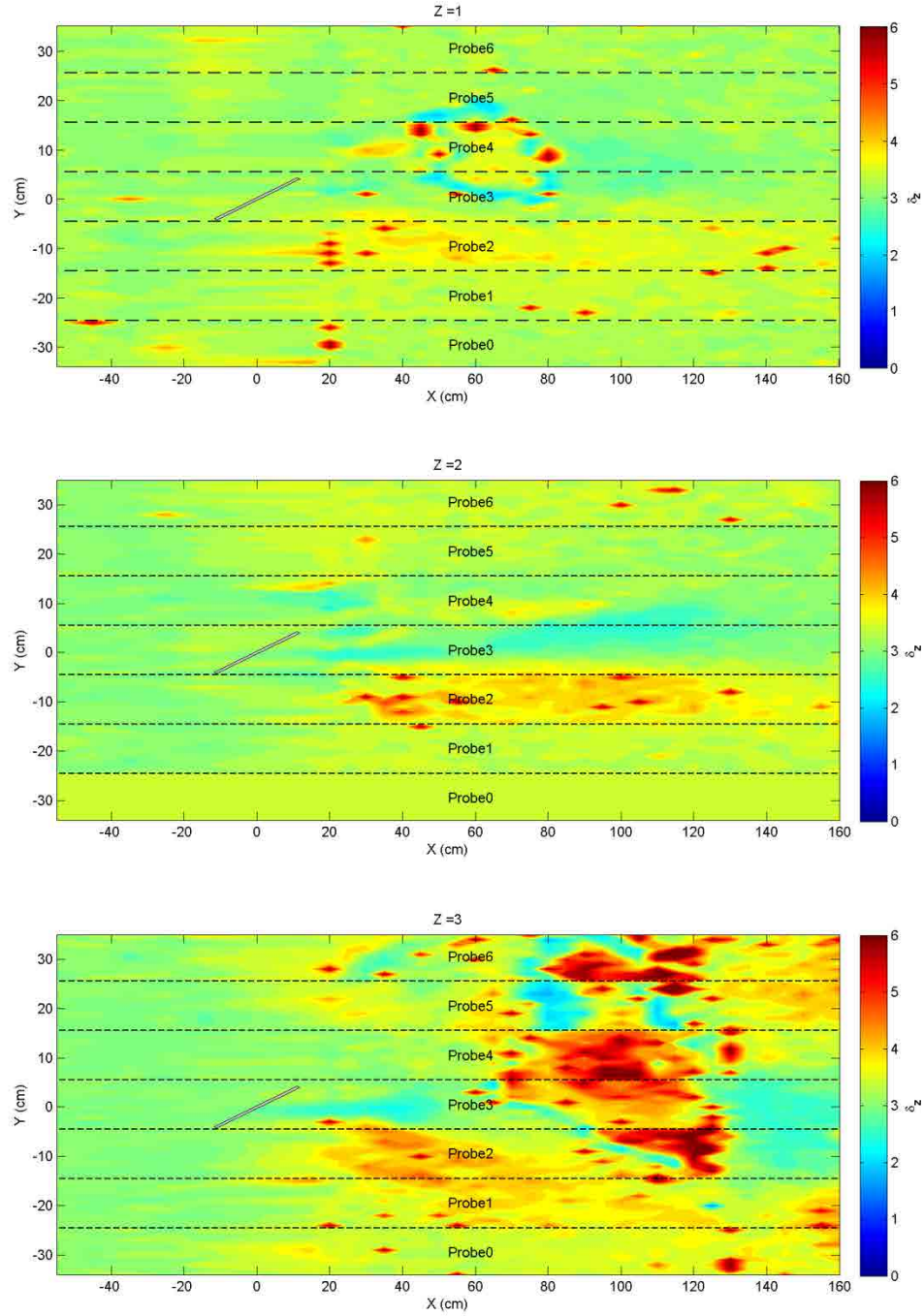


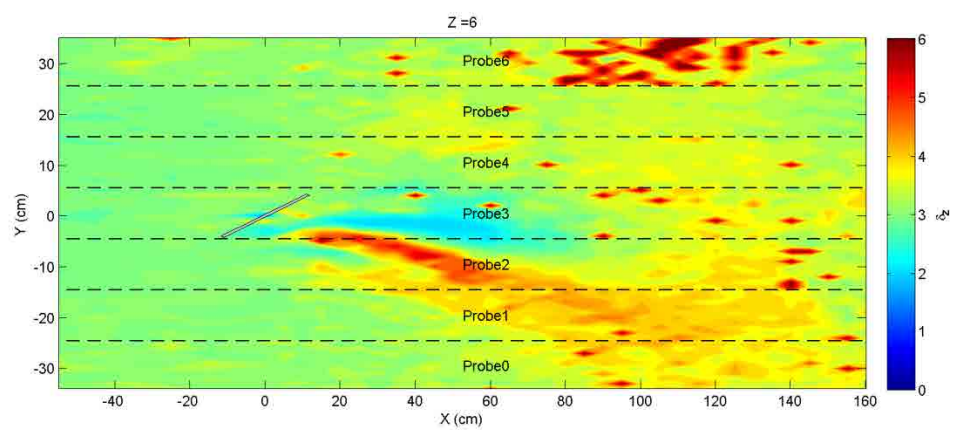
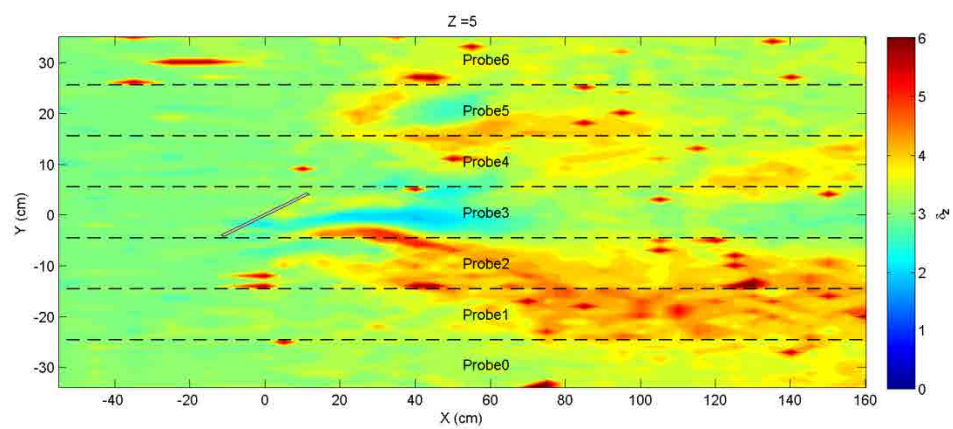
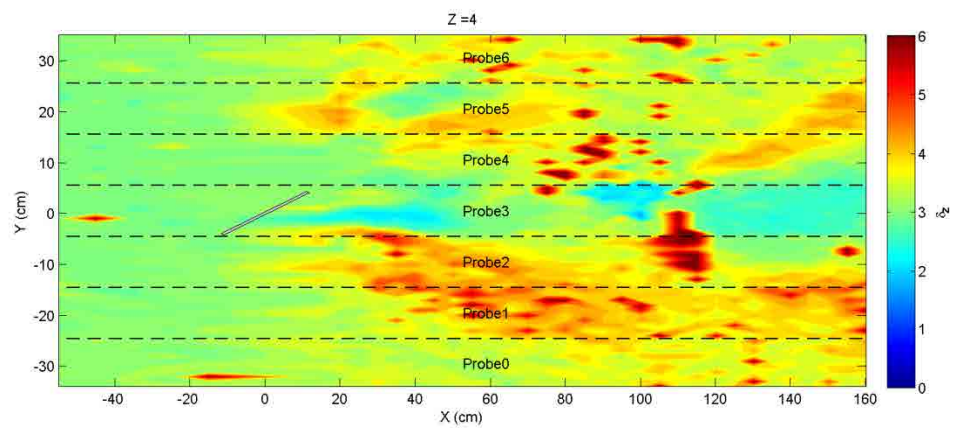


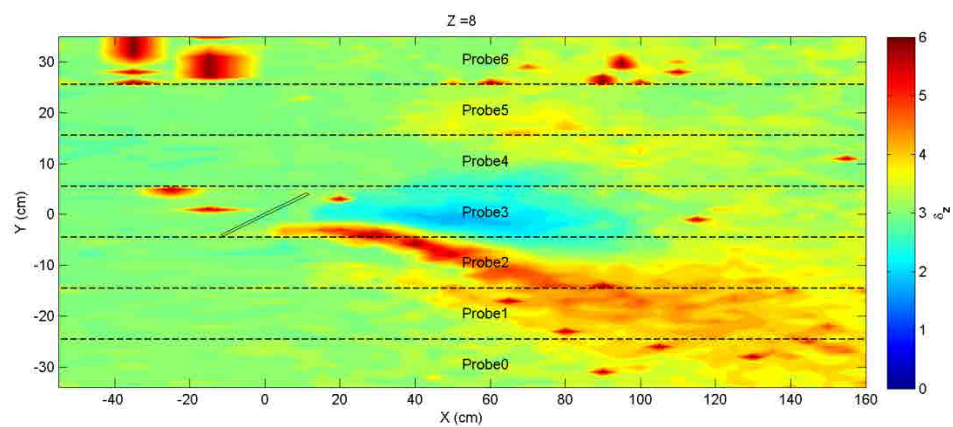
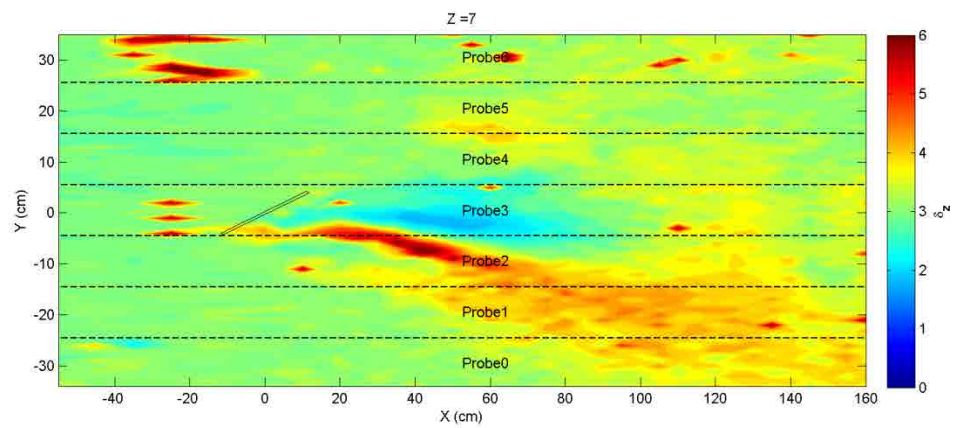




## Kurtosis Factor $\delta_z$ in x and y-Directions

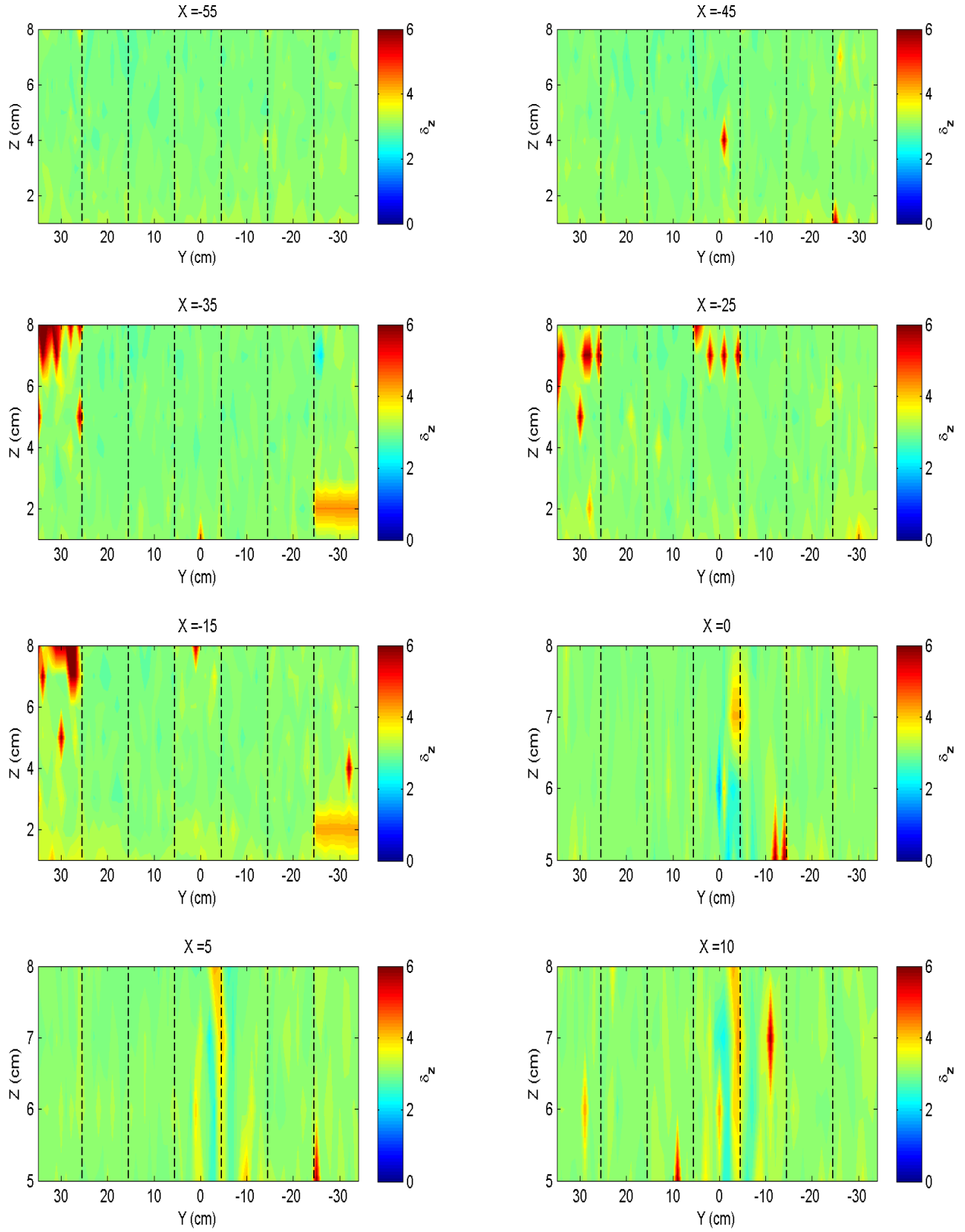


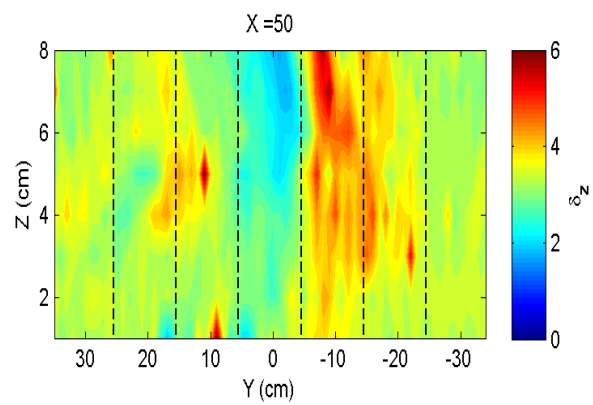
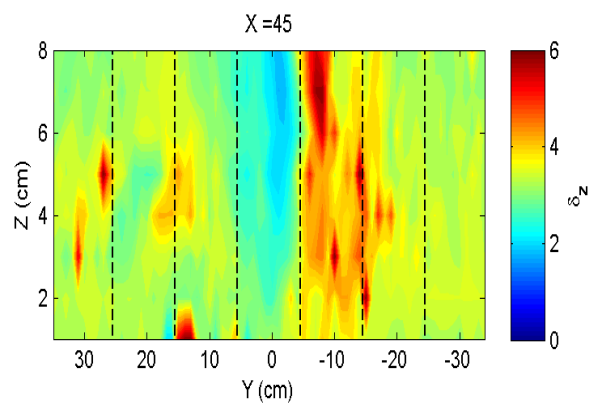
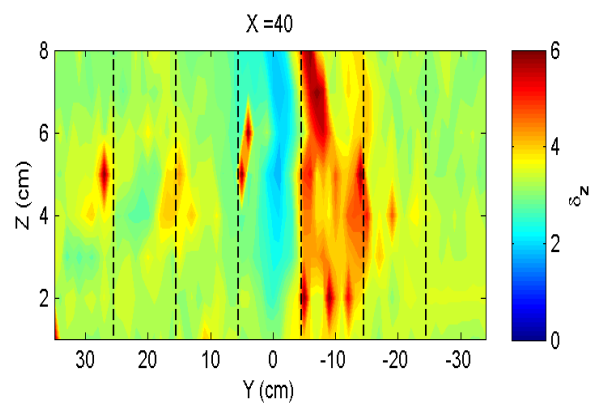
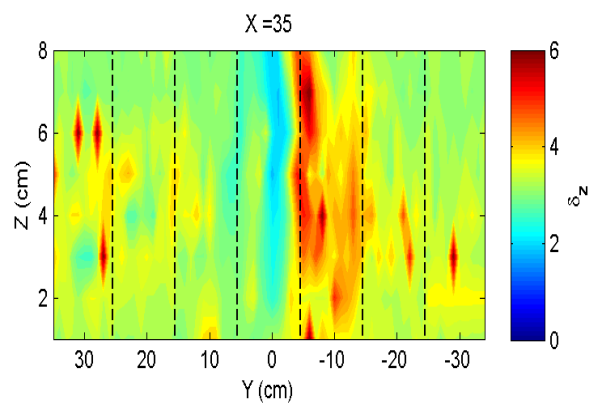
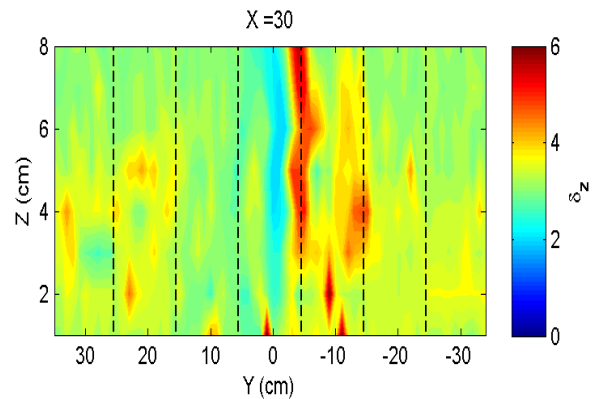
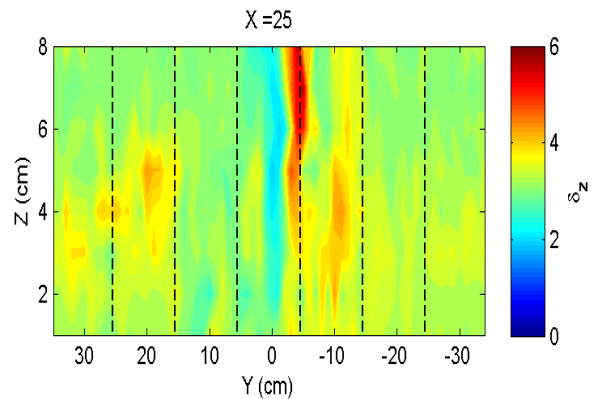
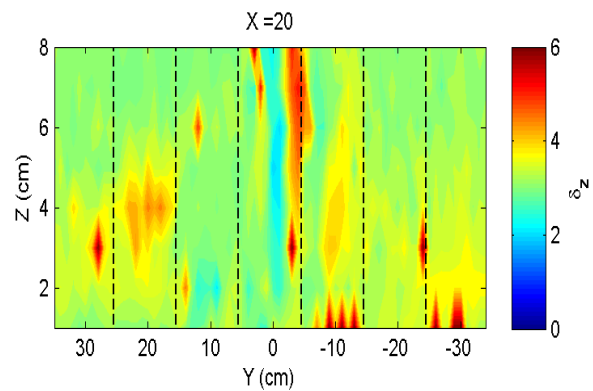
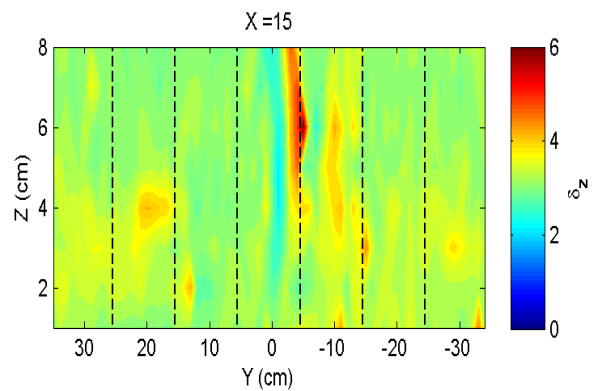




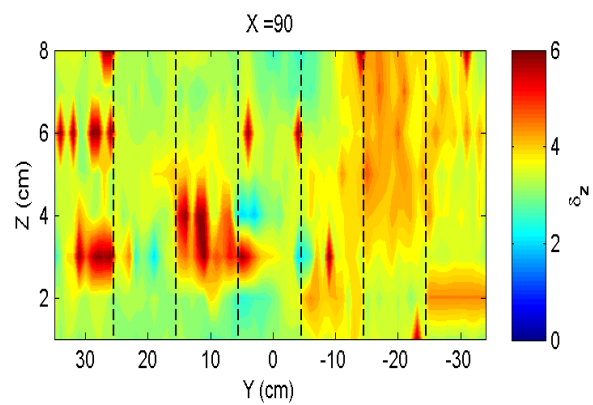
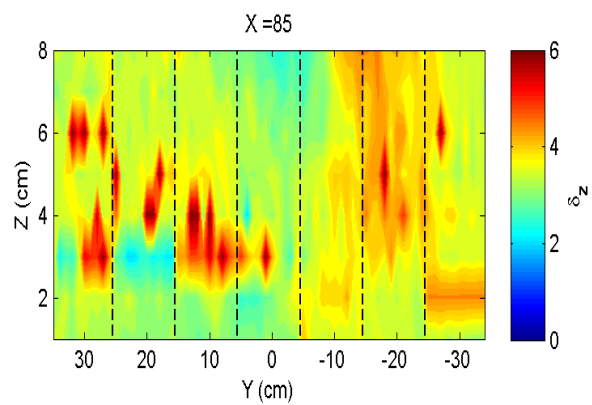
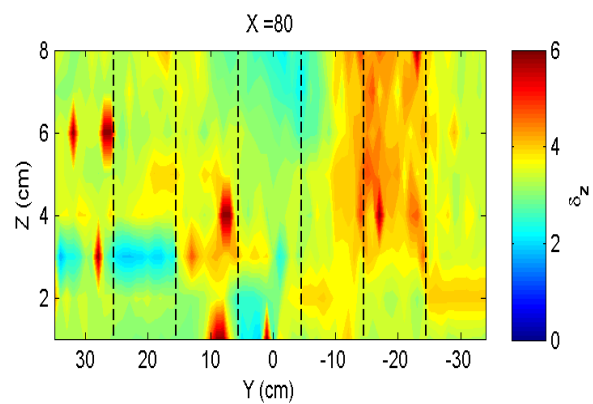
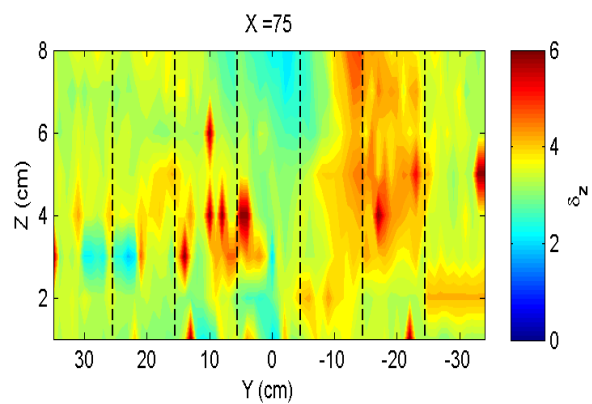
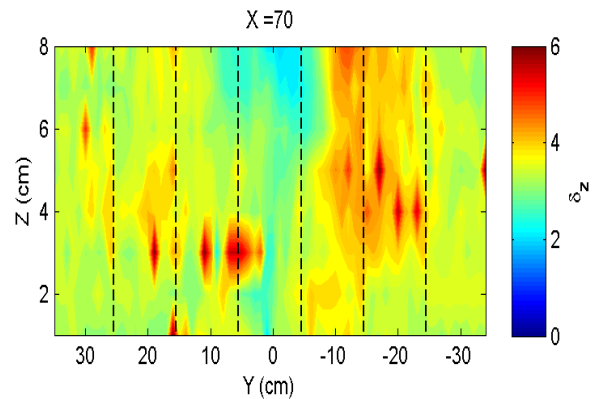
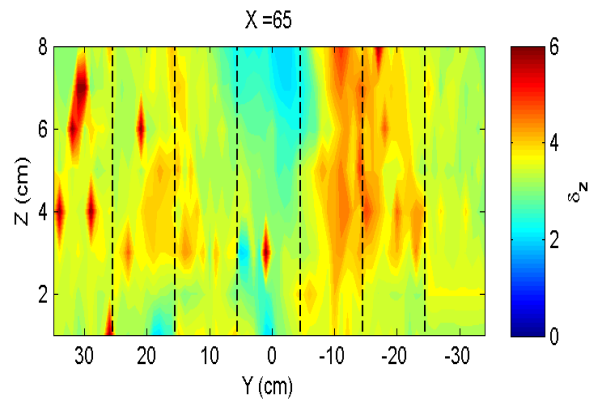
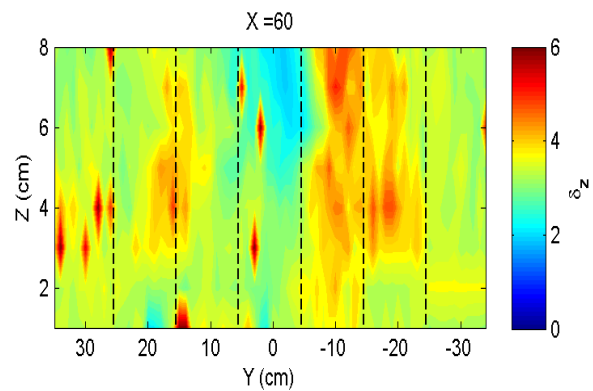
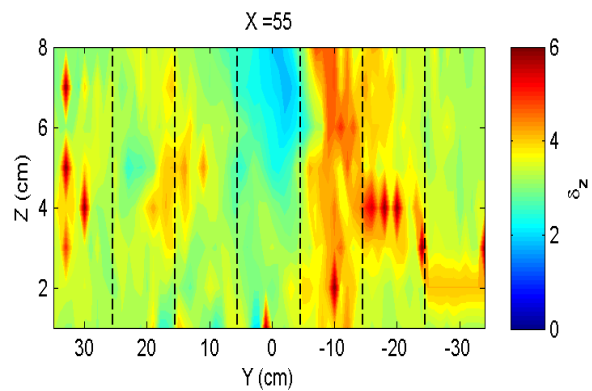


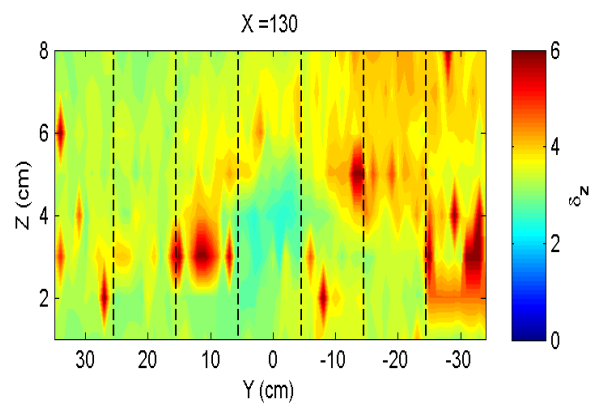
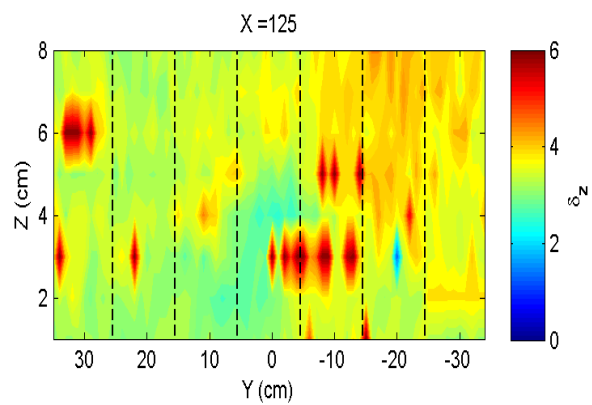
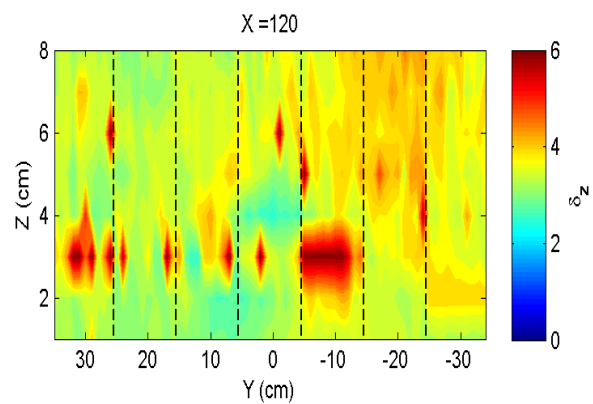
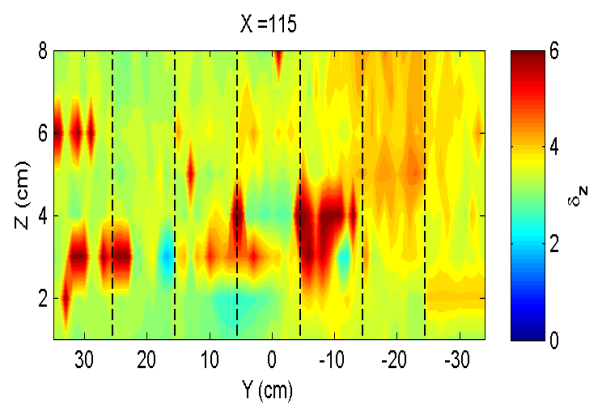
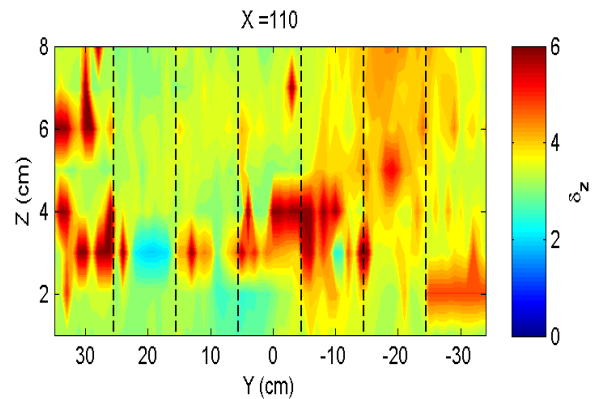
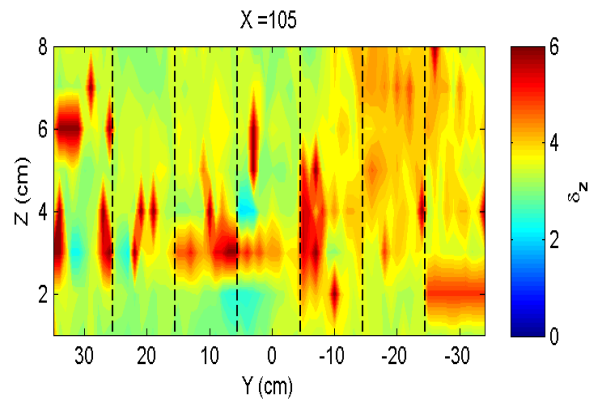
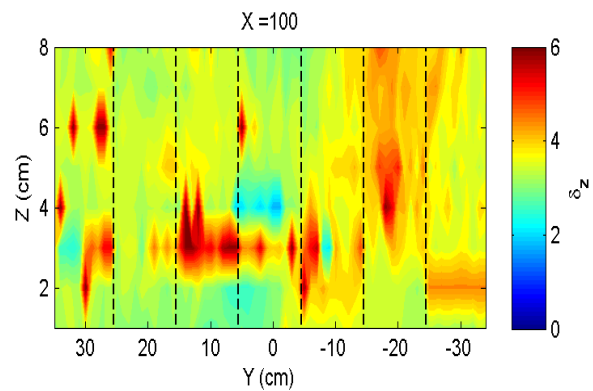
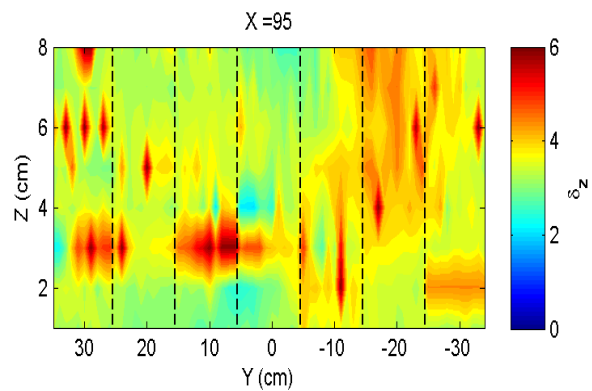
## Kurtosis Factor $\delta_z$ in y and z-Directions

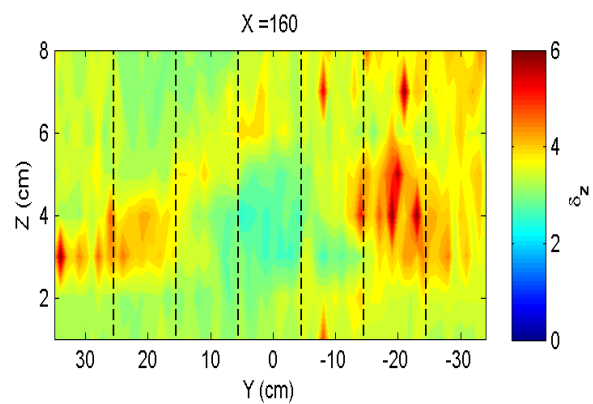
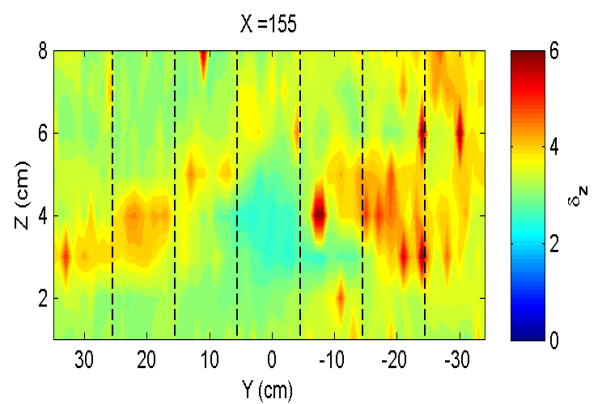
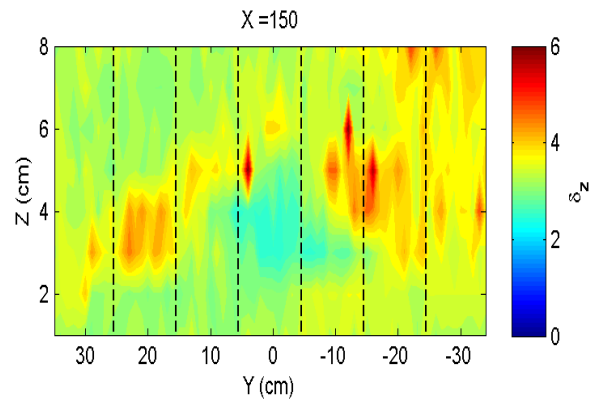
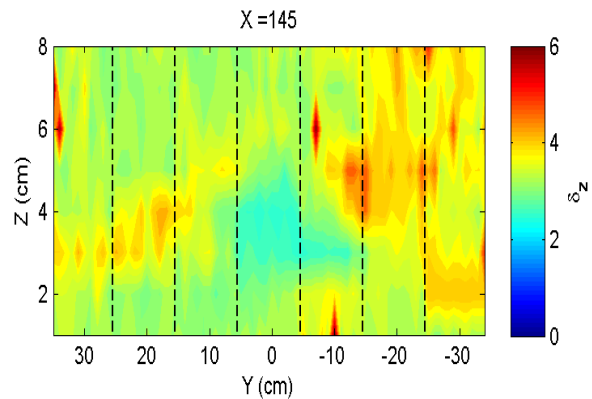
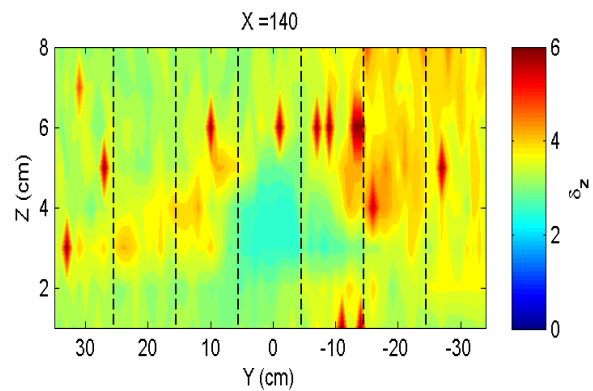
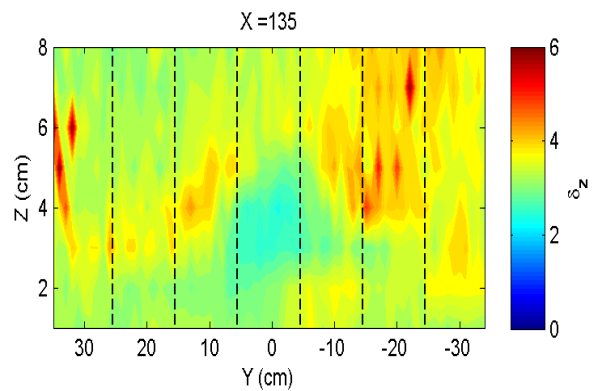




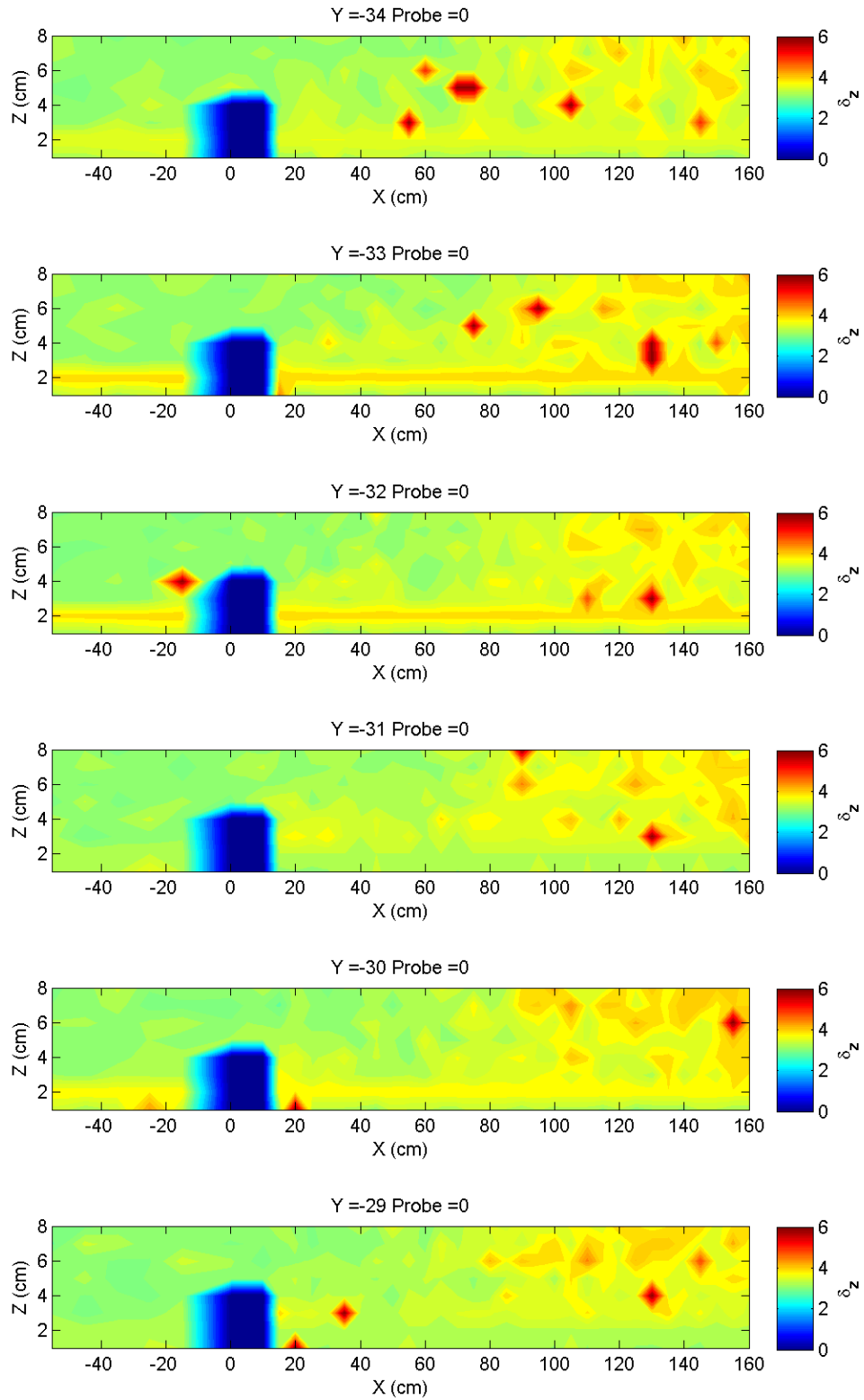


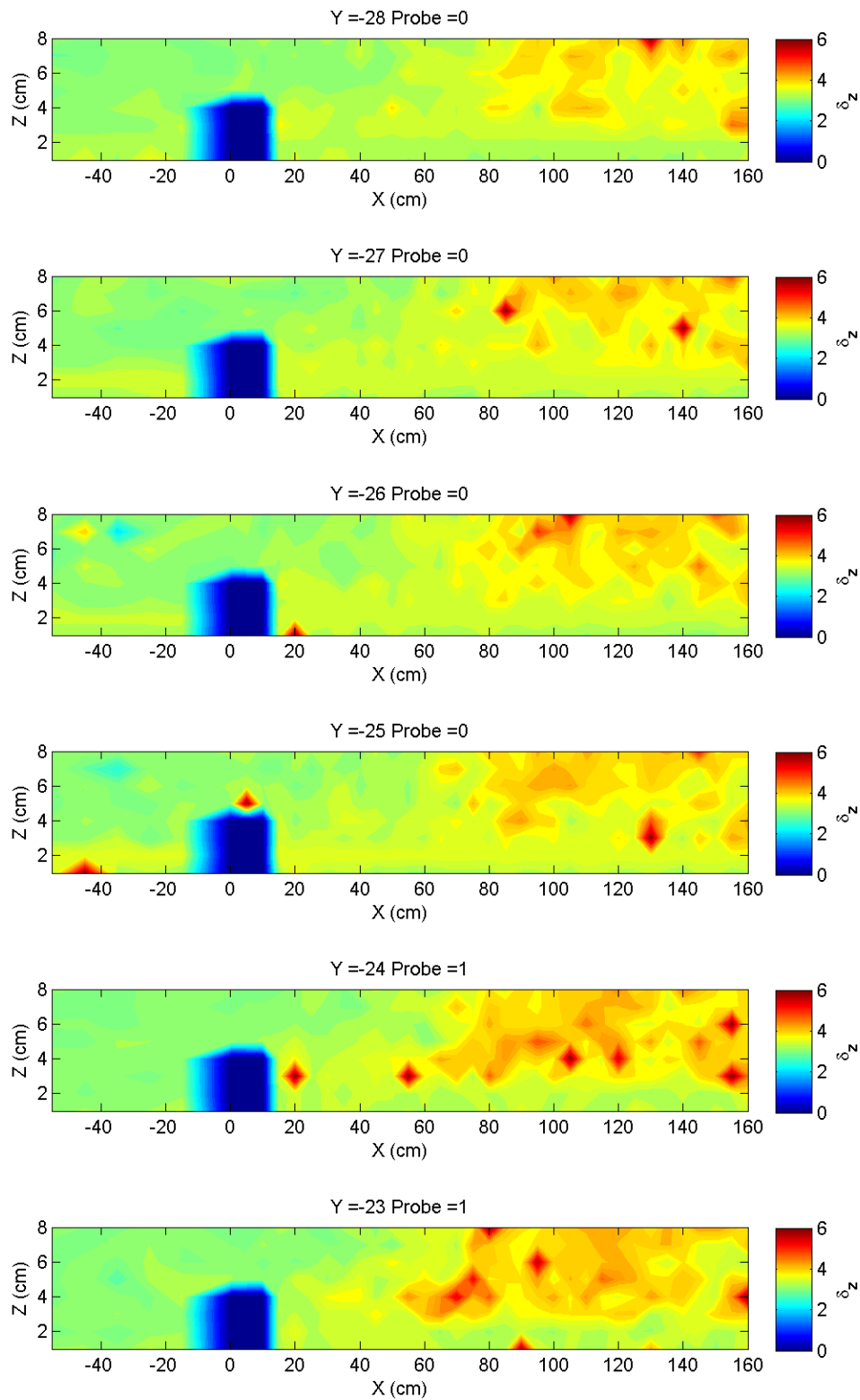


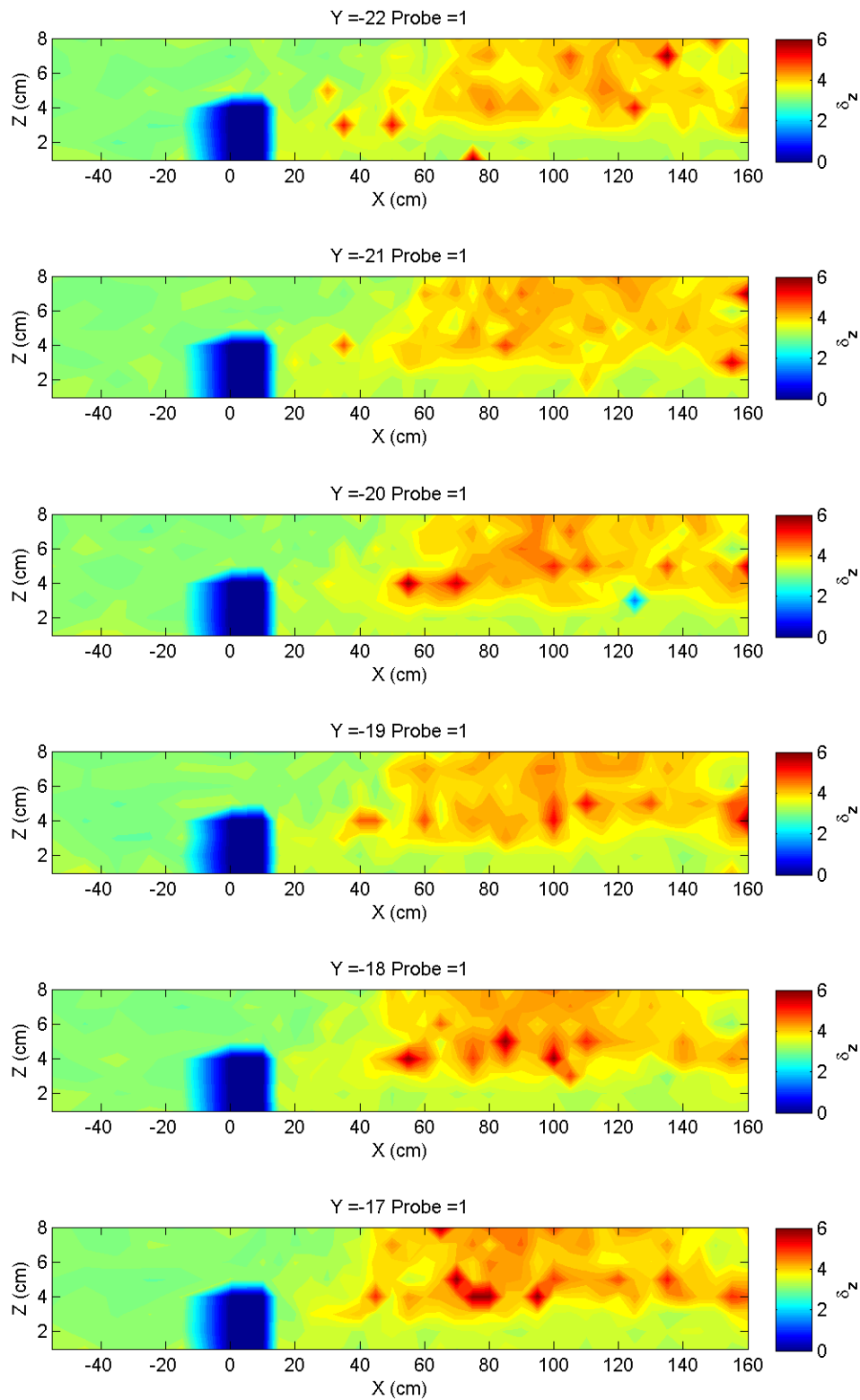


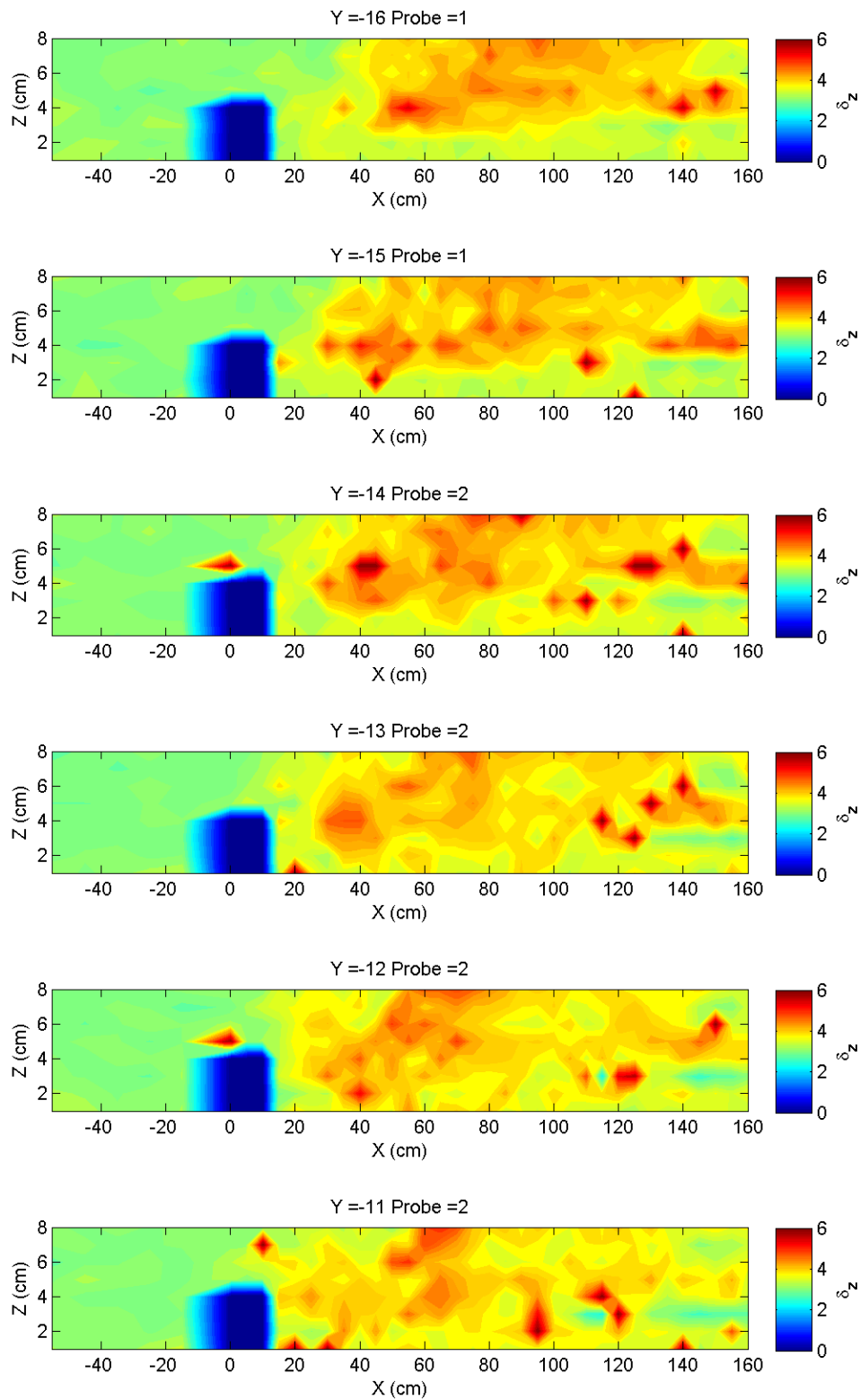


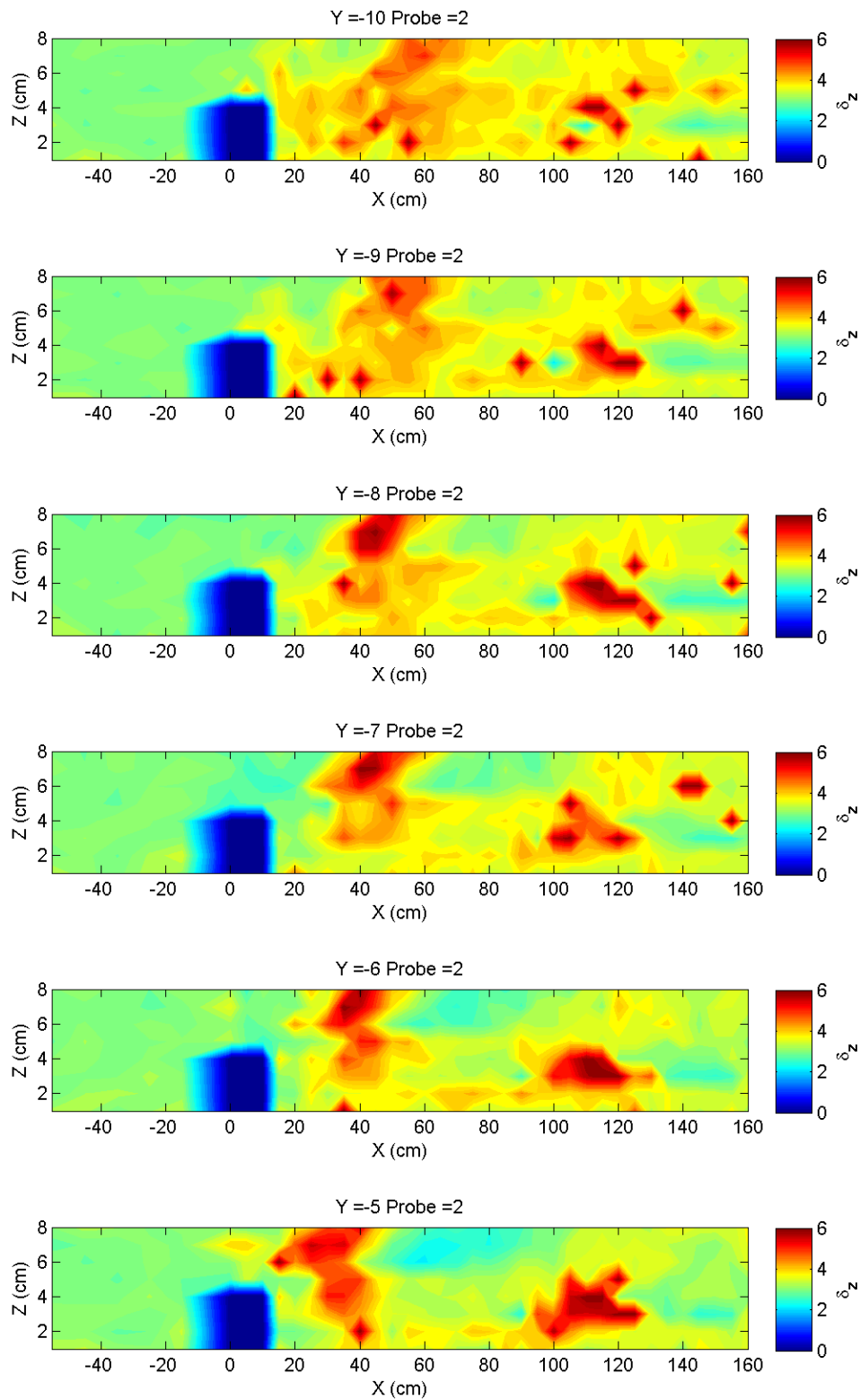
## Kurtosis Factor $\delta_z$ in x and z-Directions



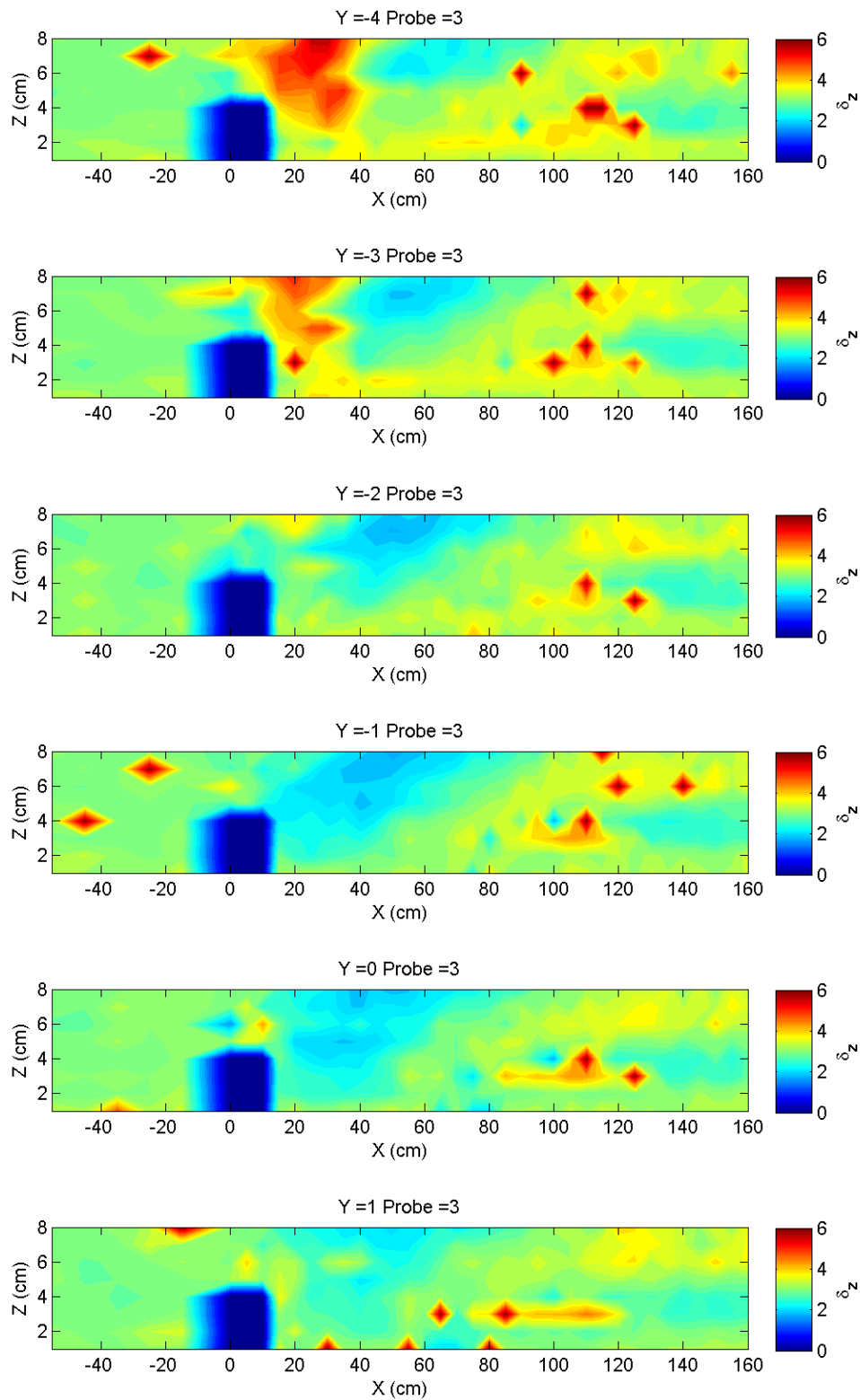


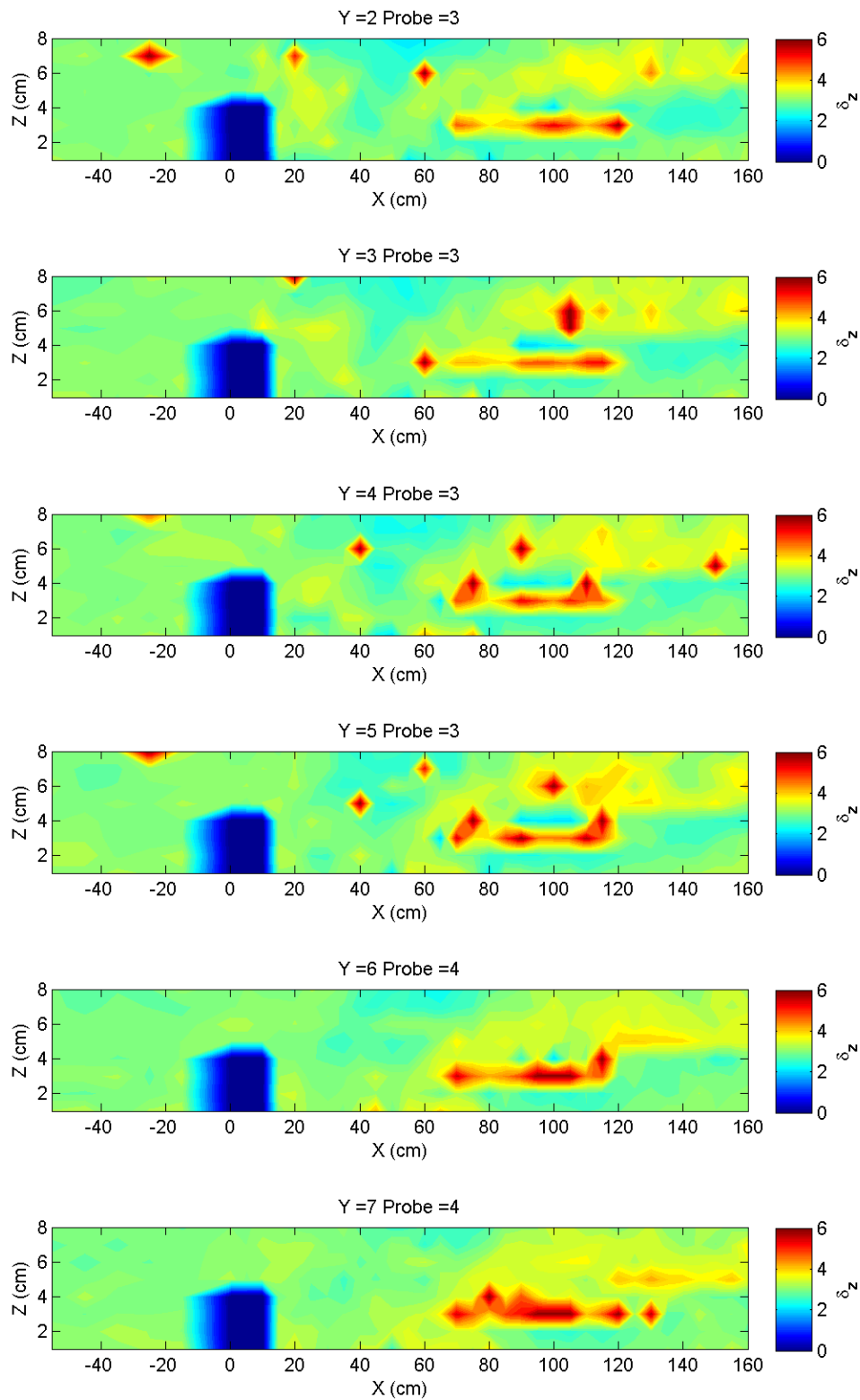


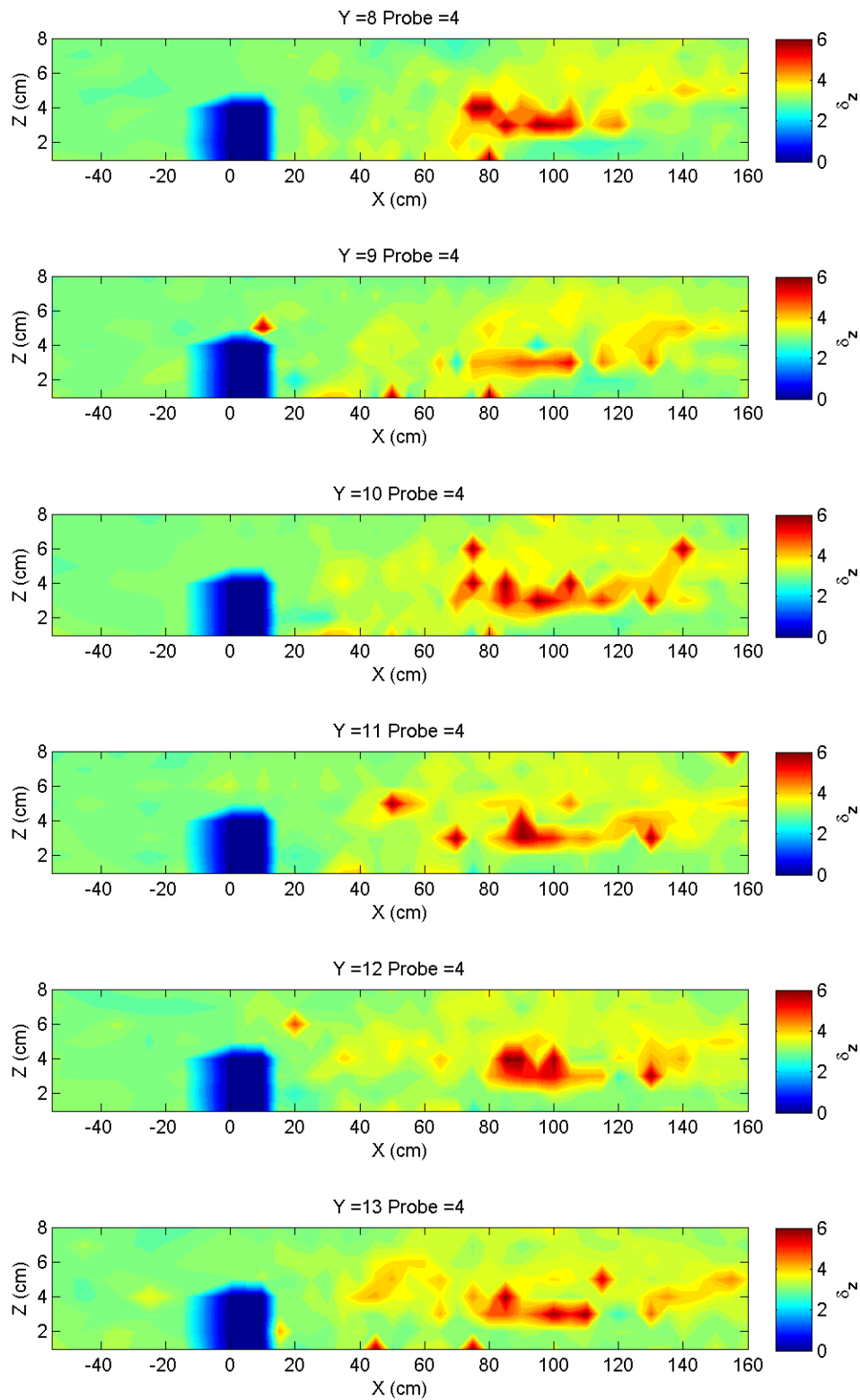


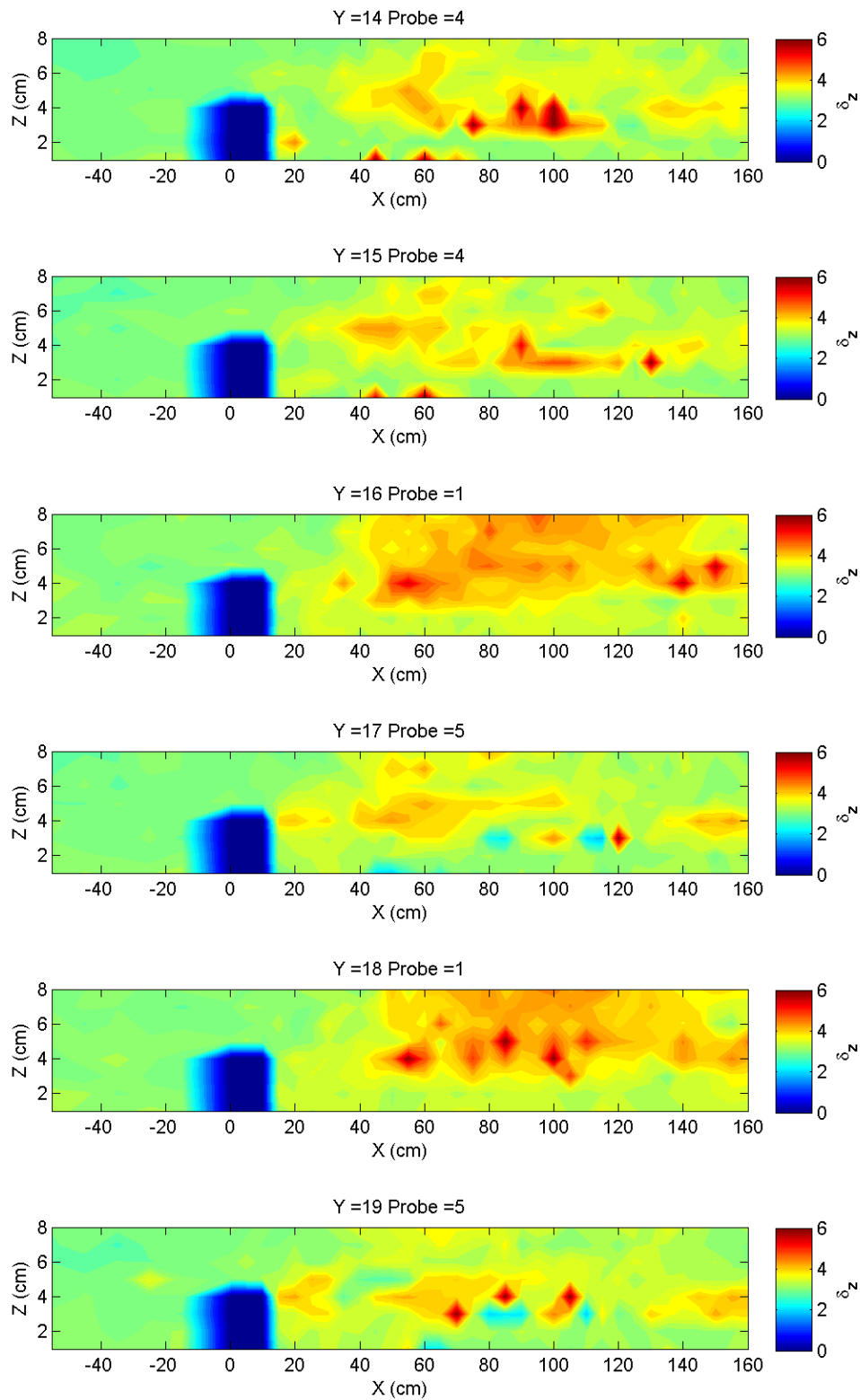


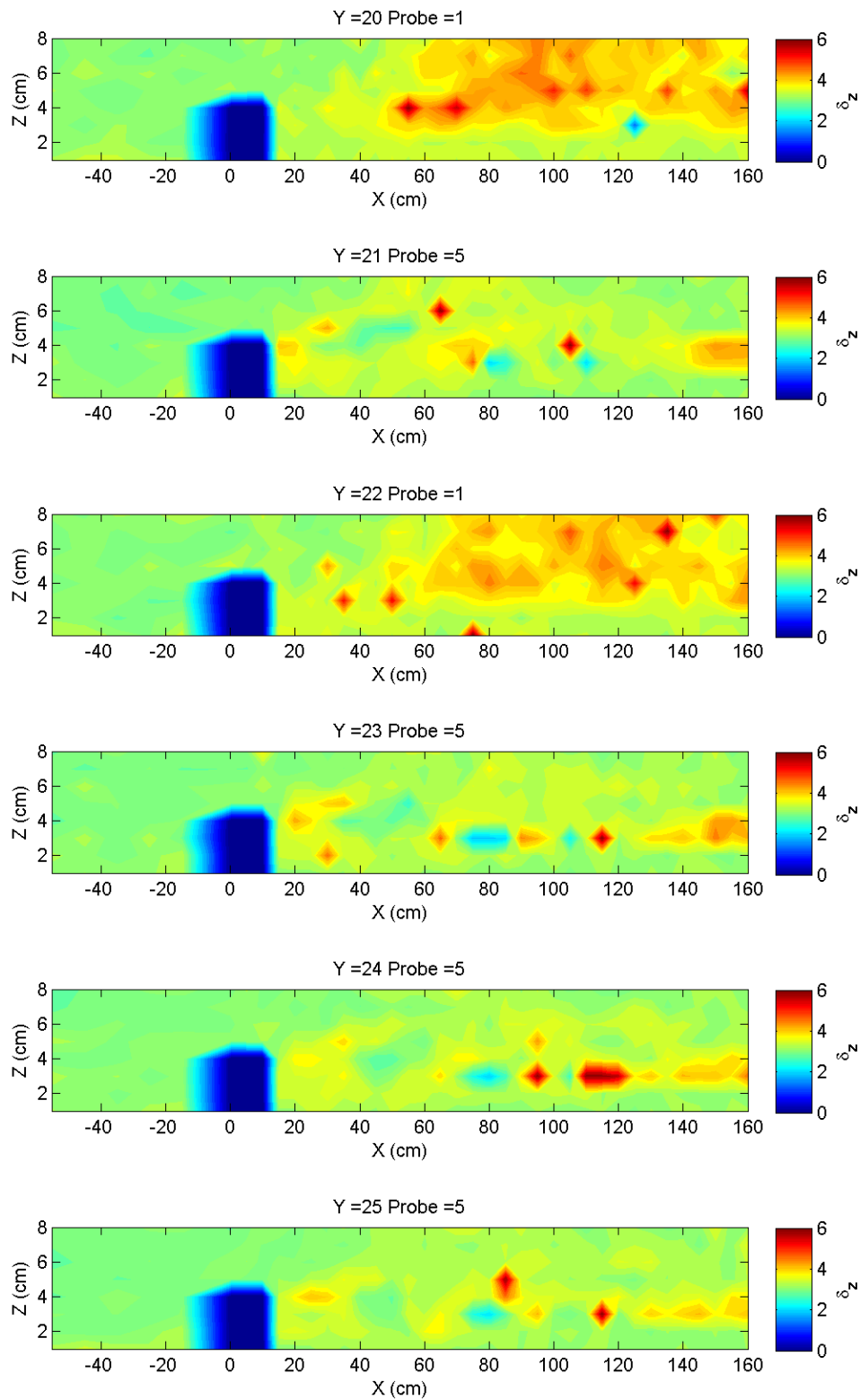


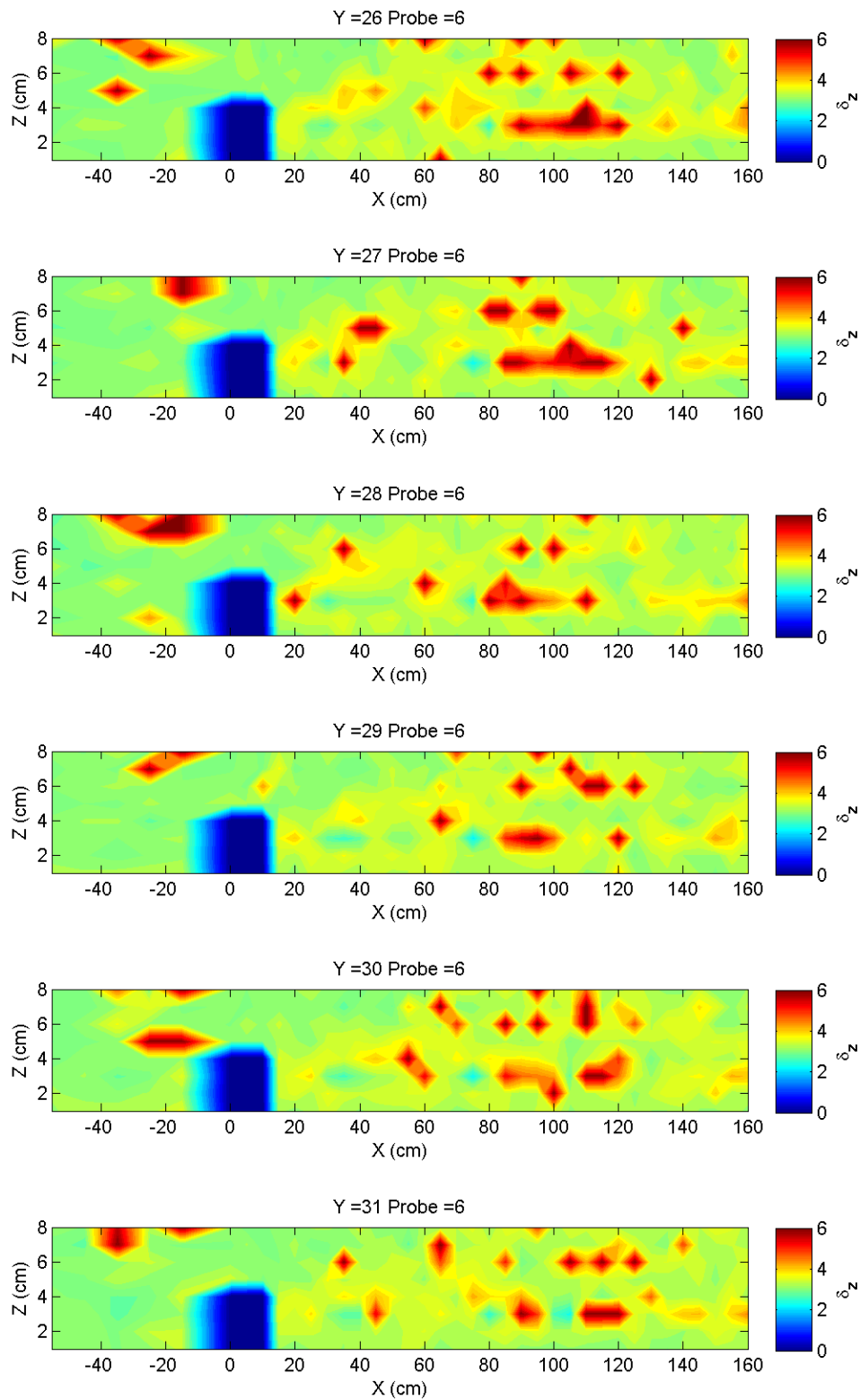


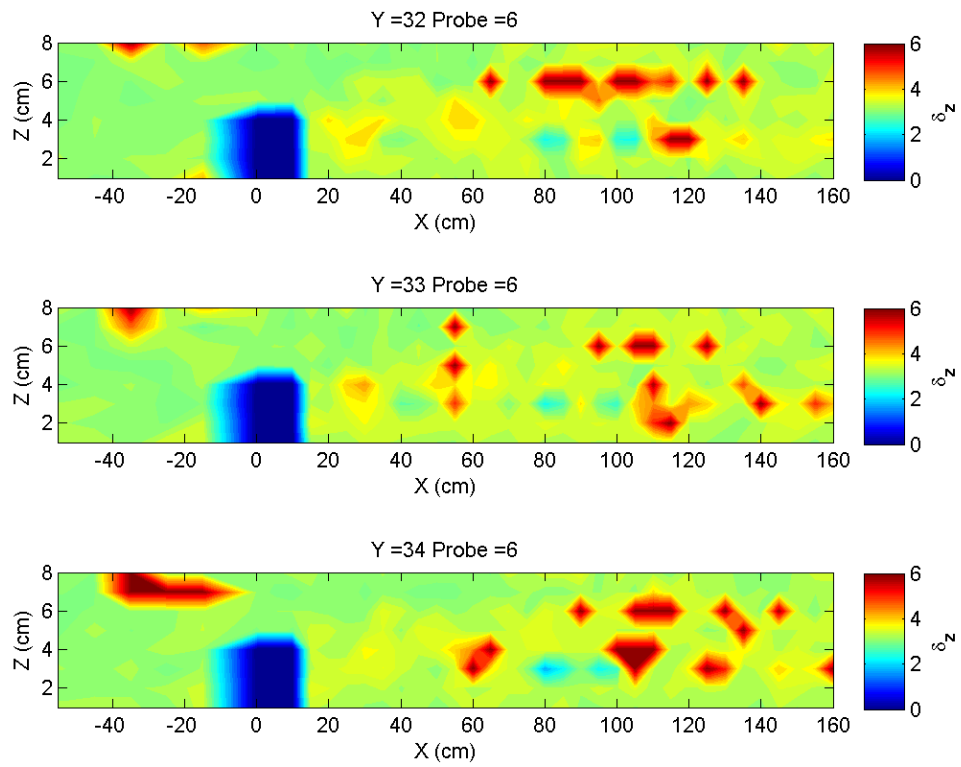








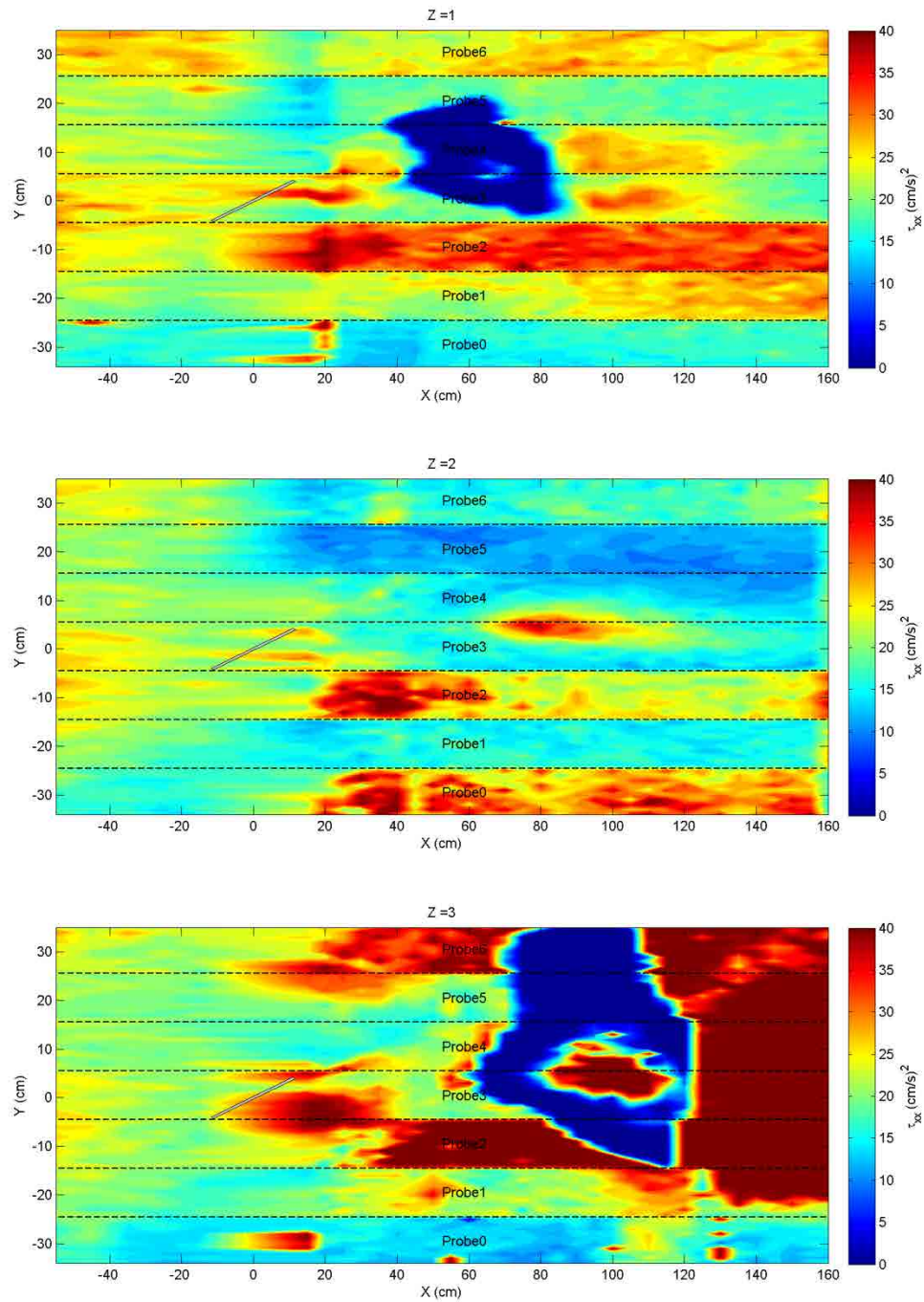




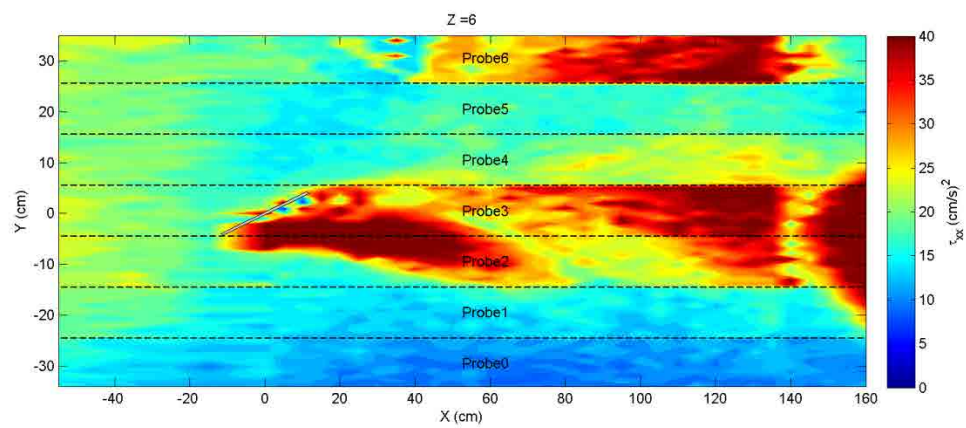
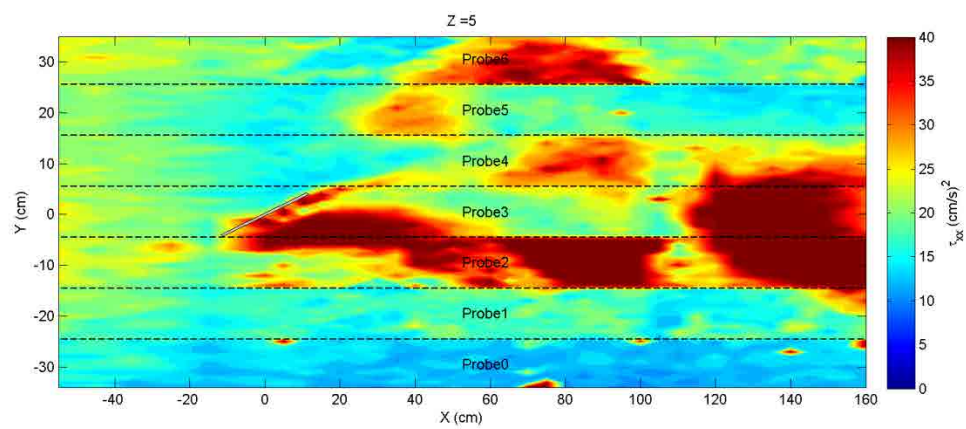
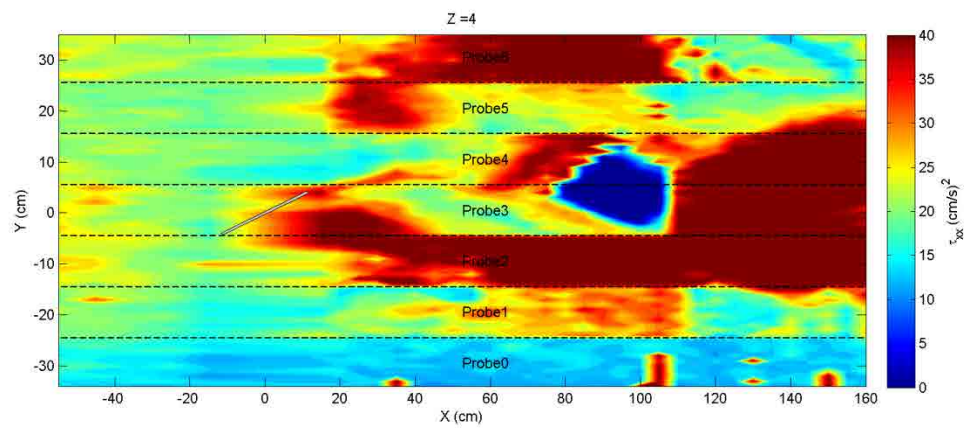
## Appendix C Results – Submerged Vanes Turbulence Statistics

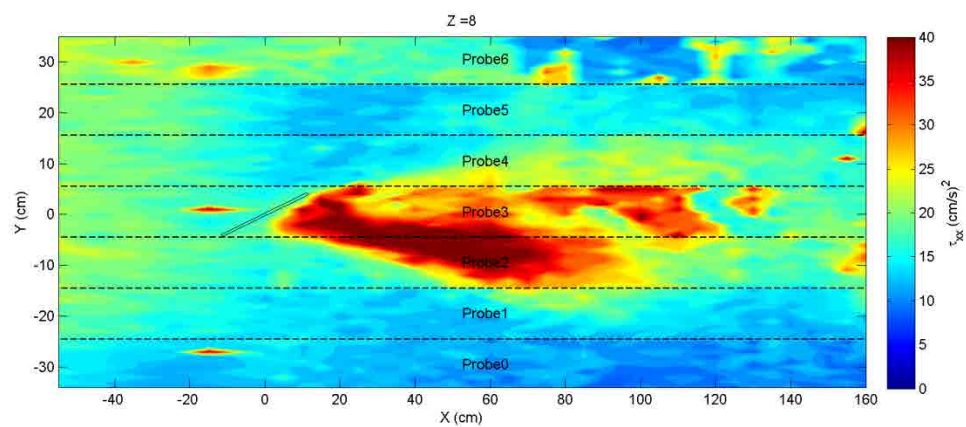
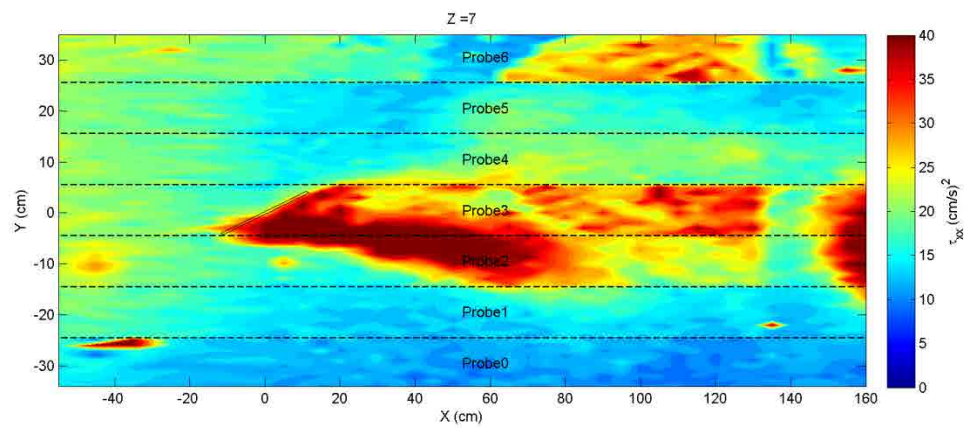
### C.2 Reynolds Normal and Shear Stresses

#### 1. Reynolds Normal Stresses $\tau_{xx}$ in x and y-Directions

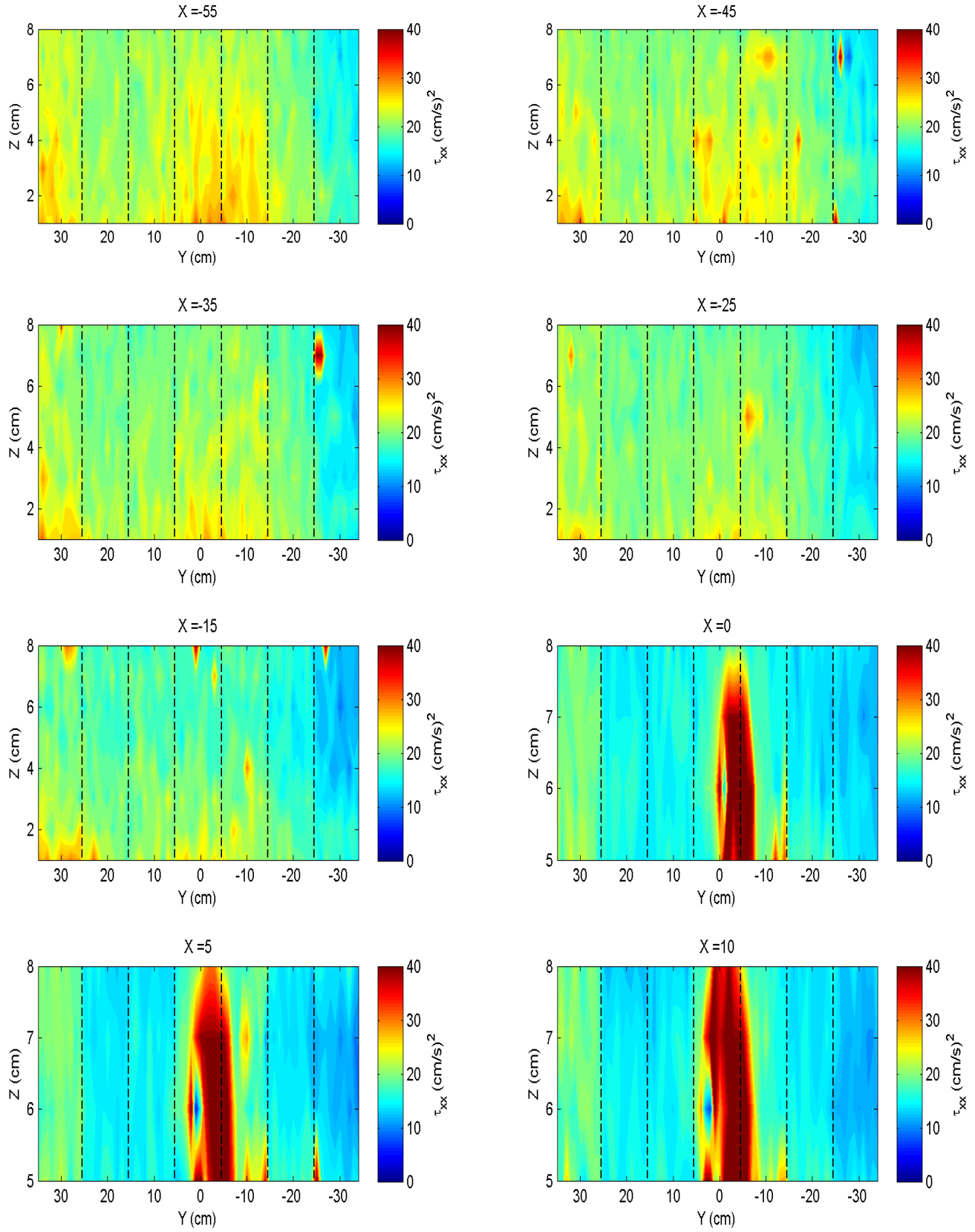


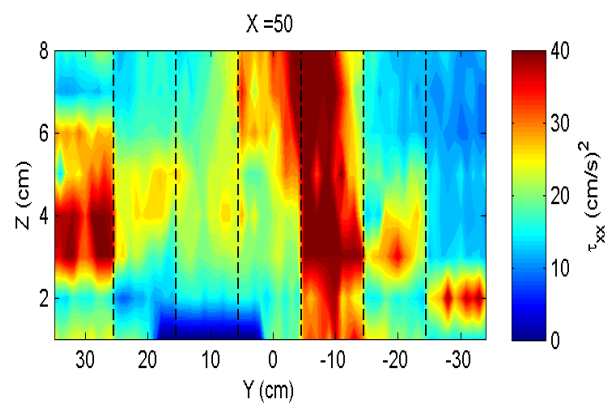
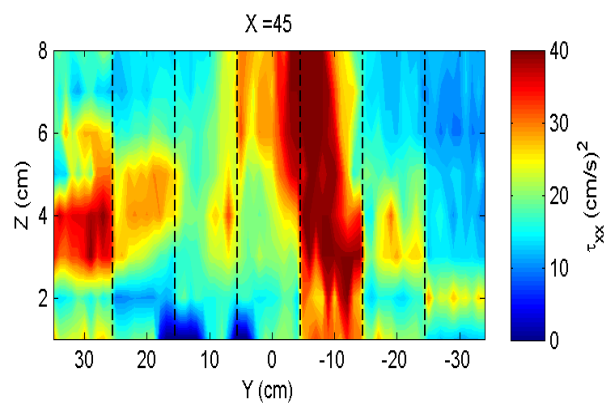
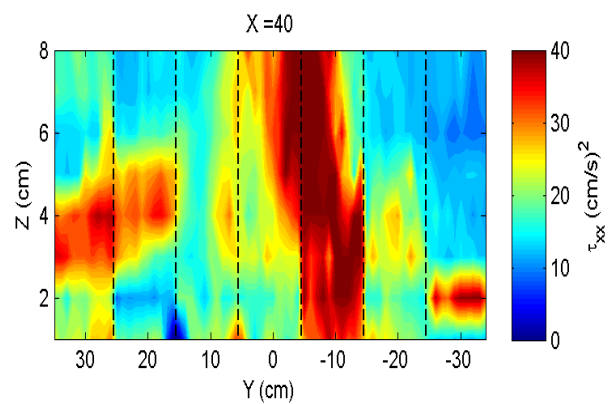
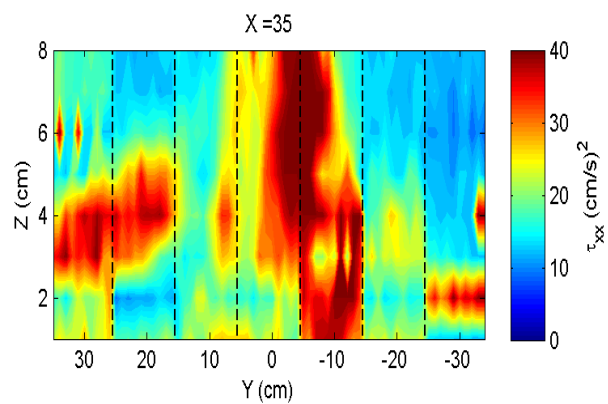
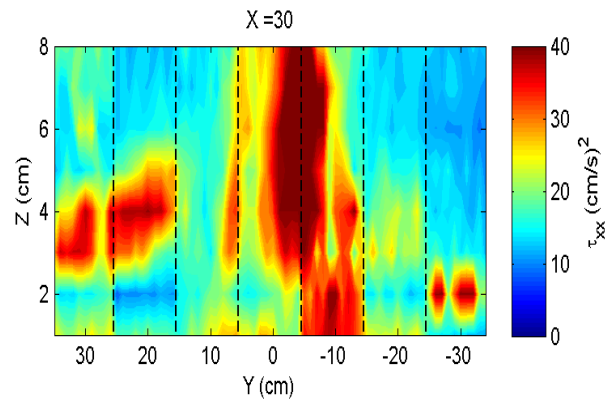
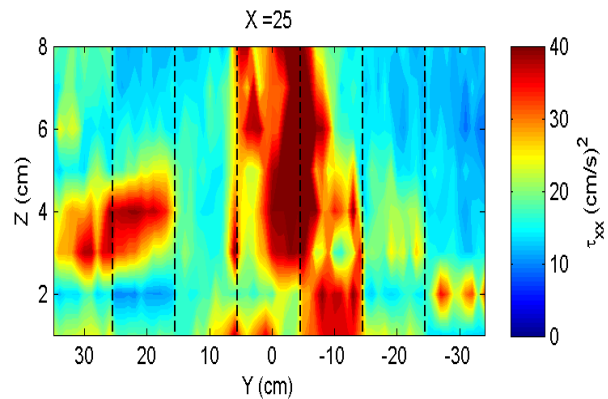
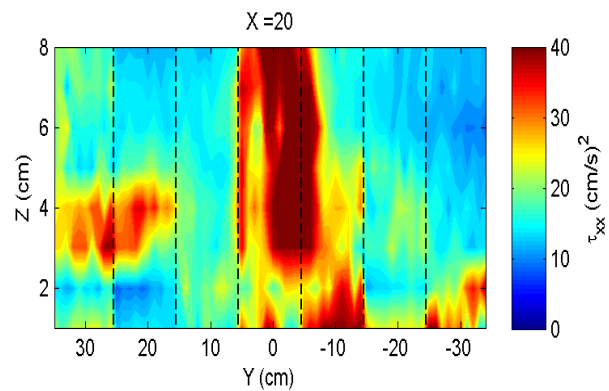
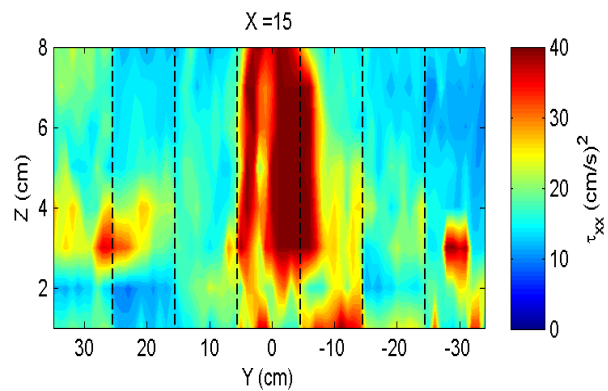




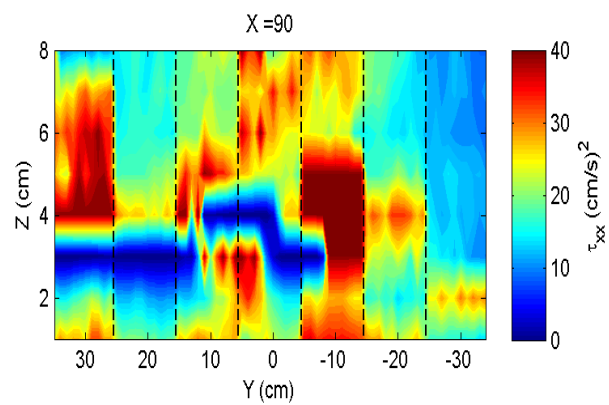
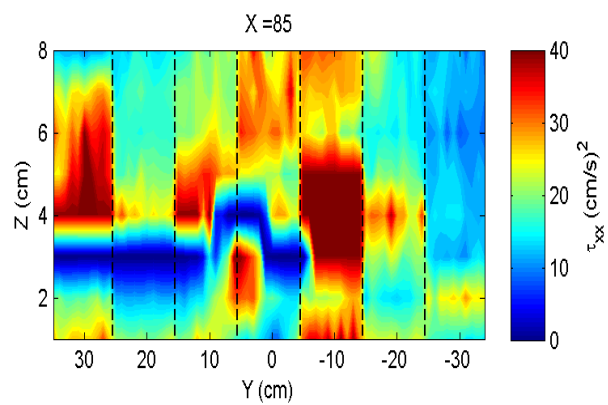
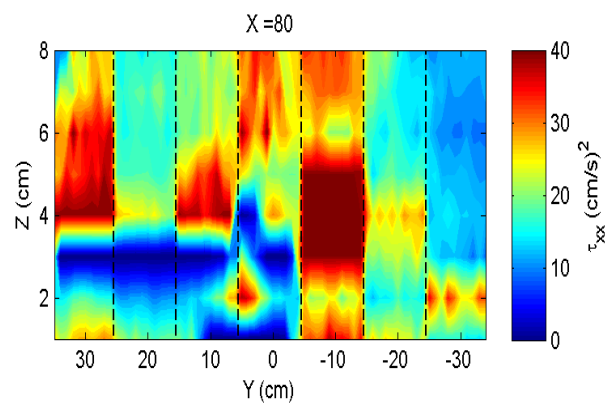
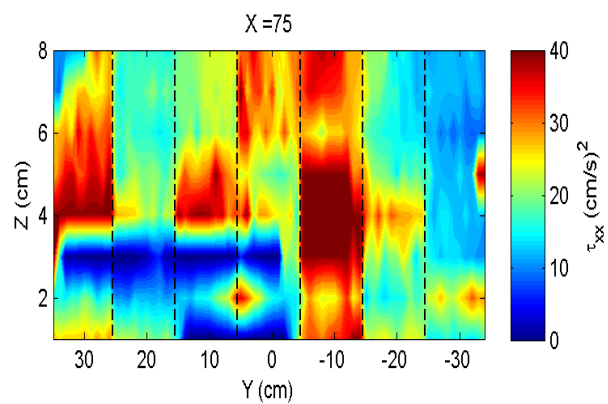
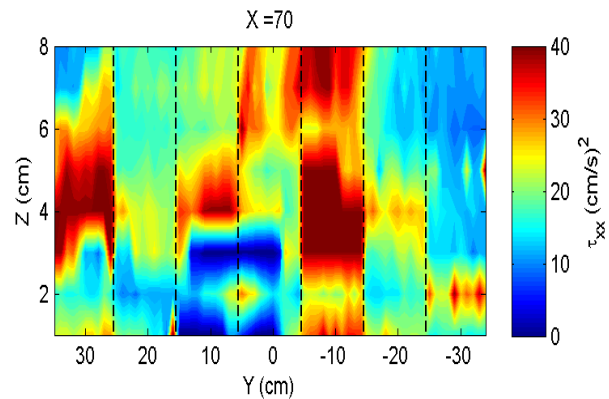
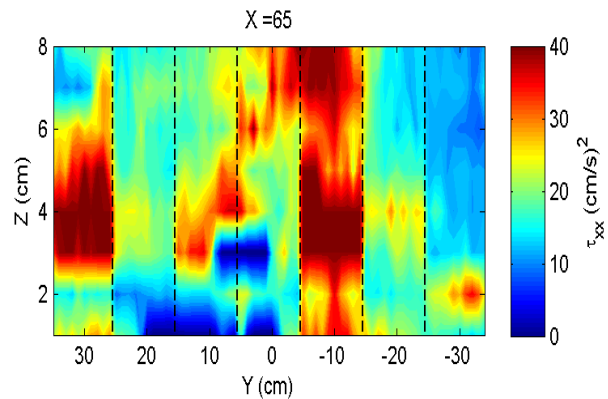
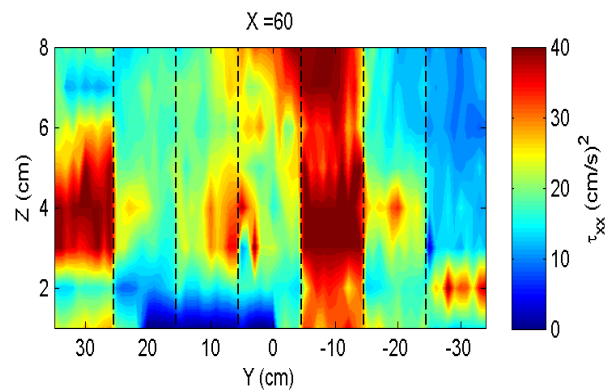
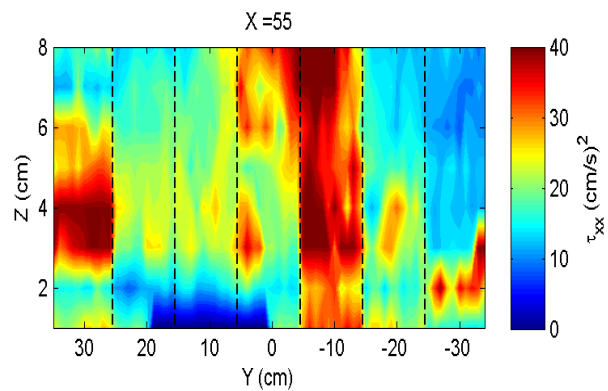


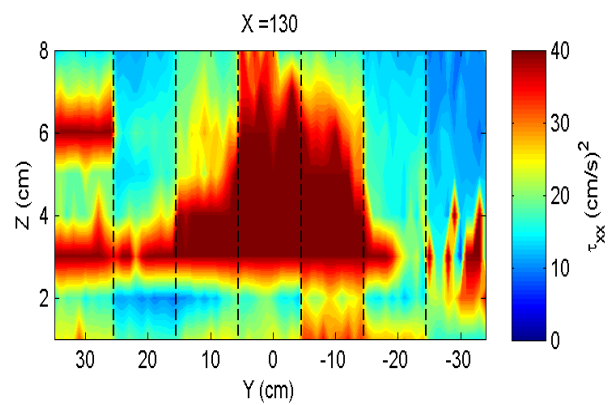
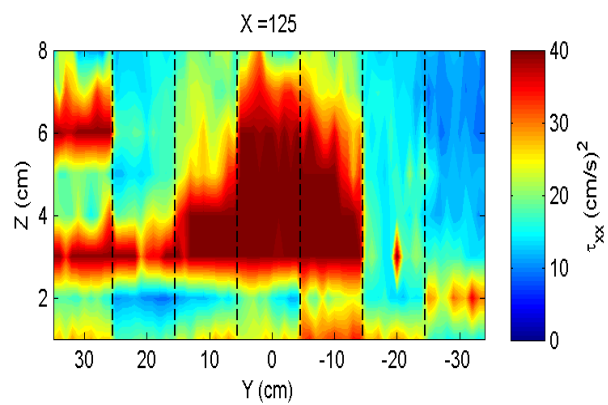
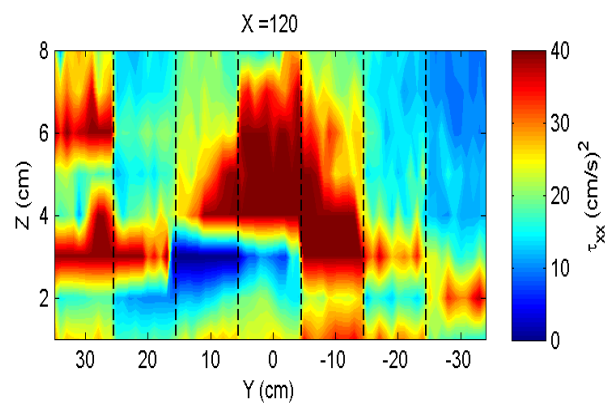
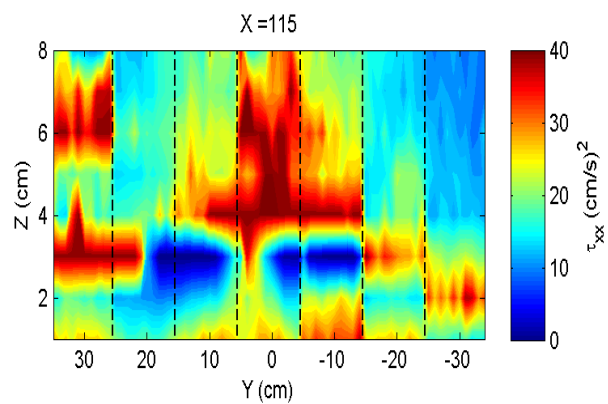
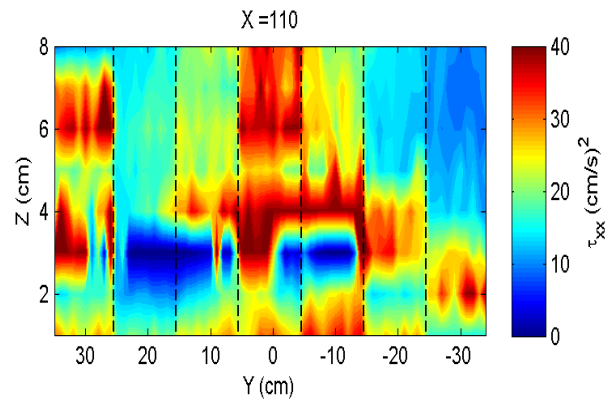
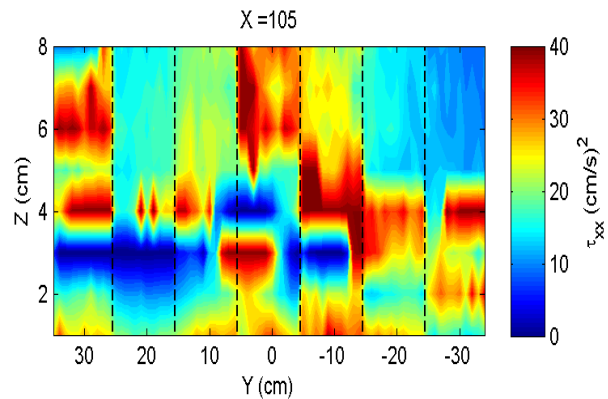
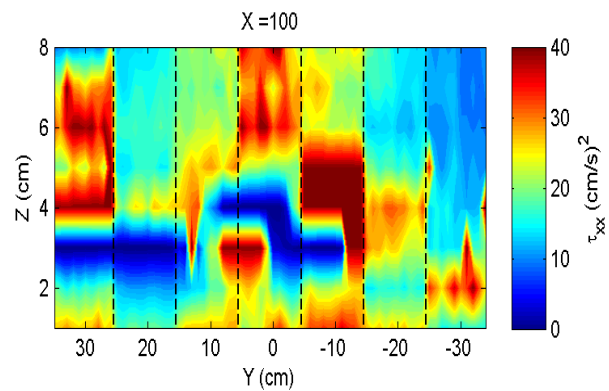
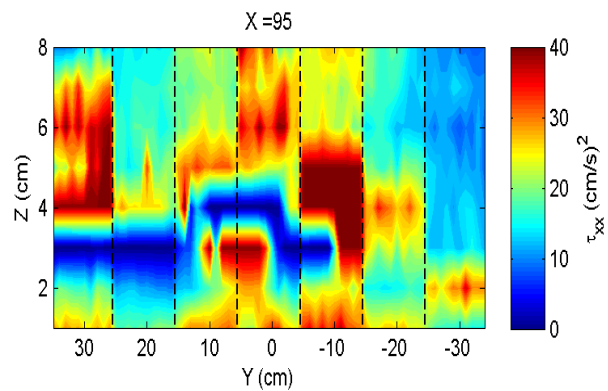
## 2. Reynolds Normal Stresses $\tau_{xx}$ in y and z-Directions

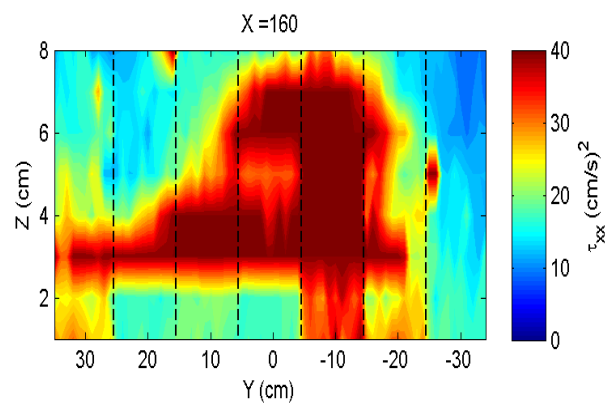
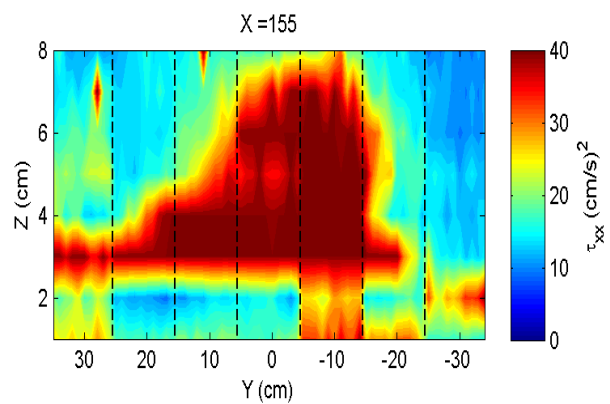
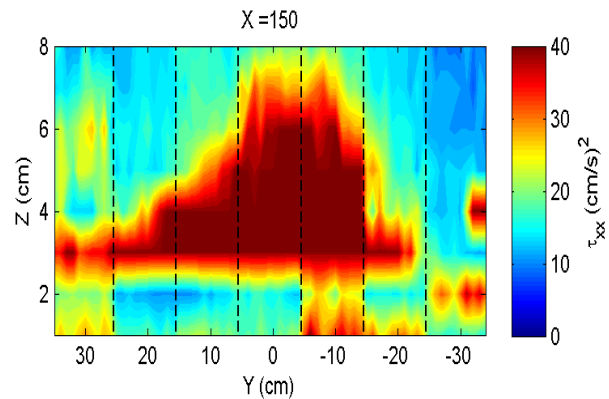
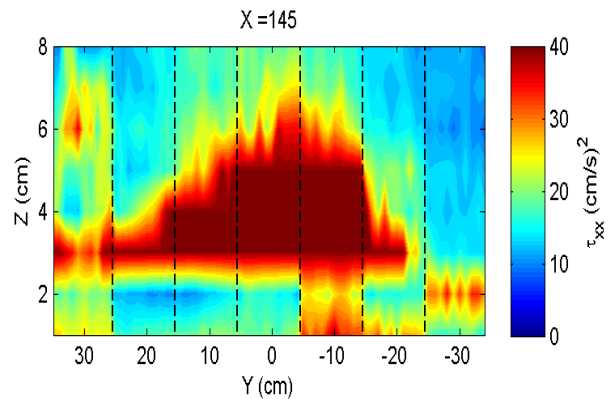
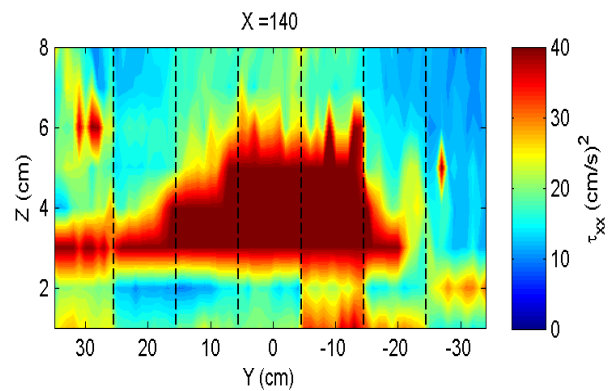
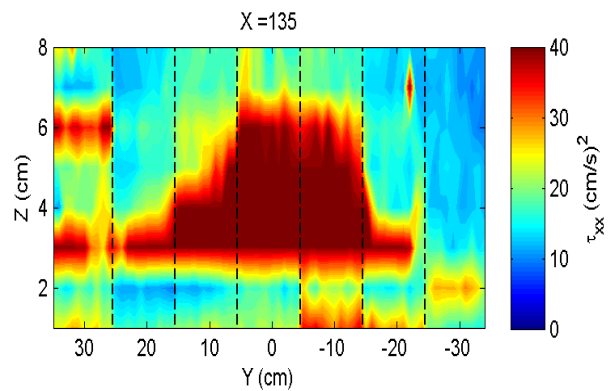




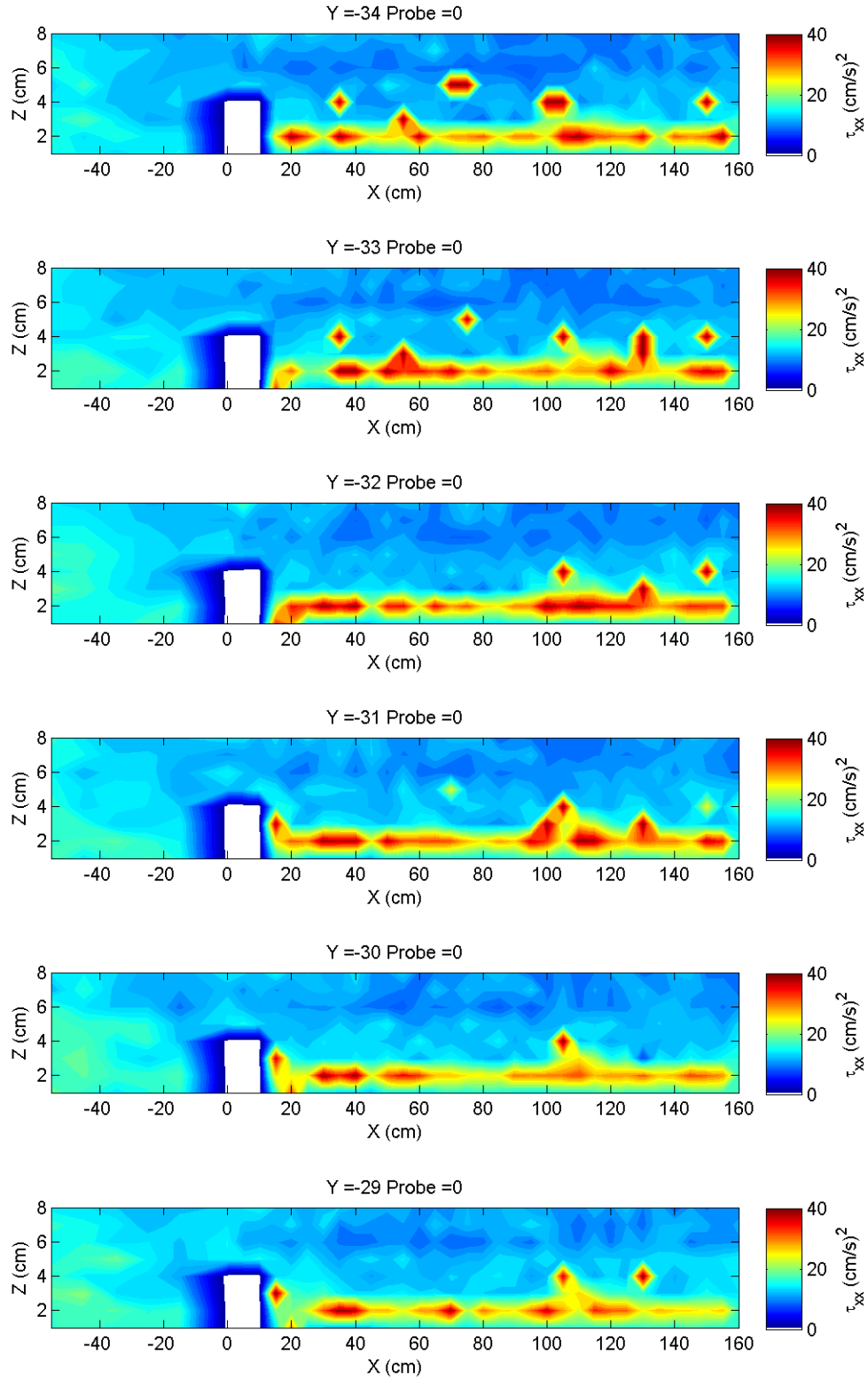




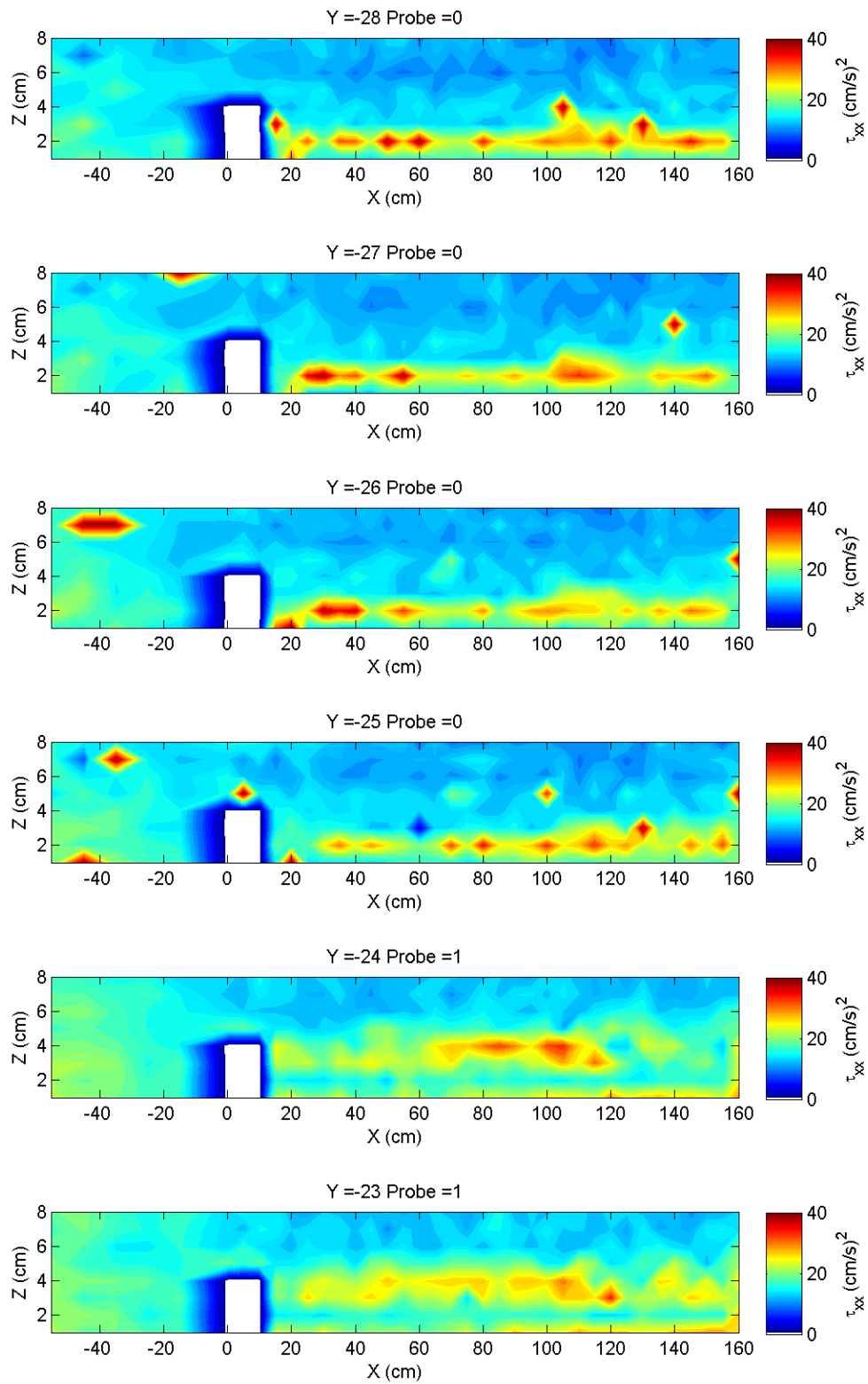


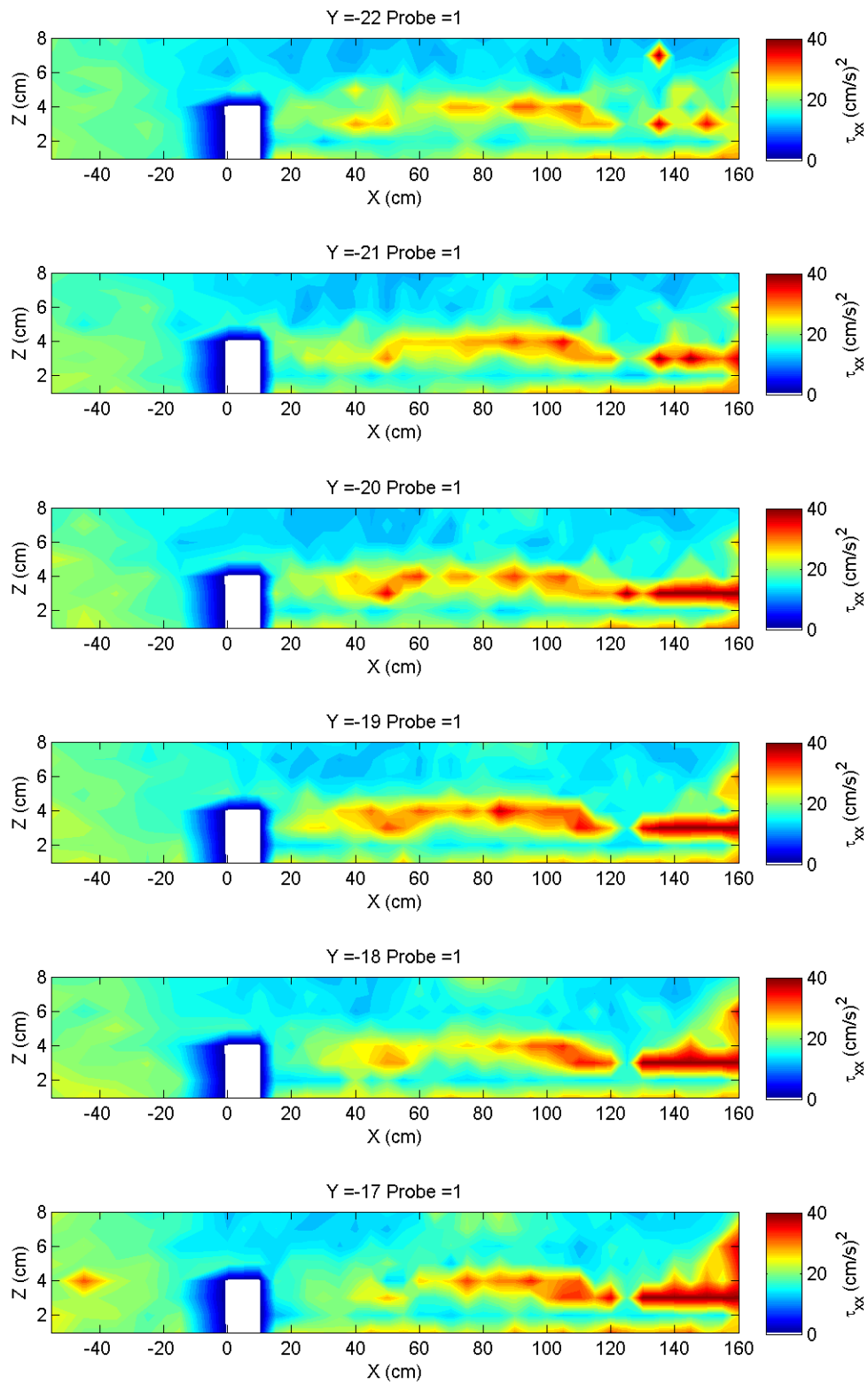


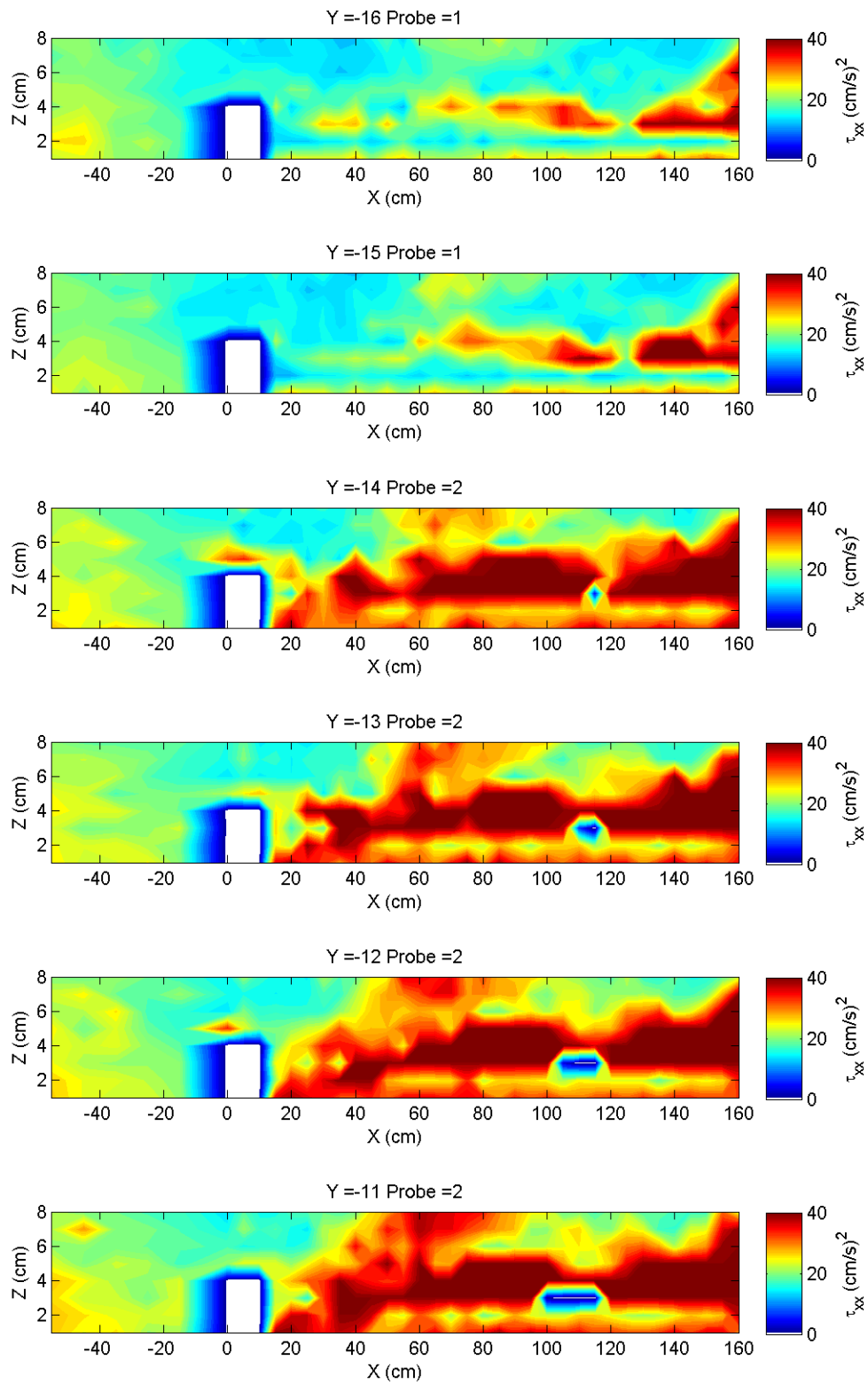
### 3. Reynolds Normal Stresses $\tau_{xx}$ in x and z-Directions

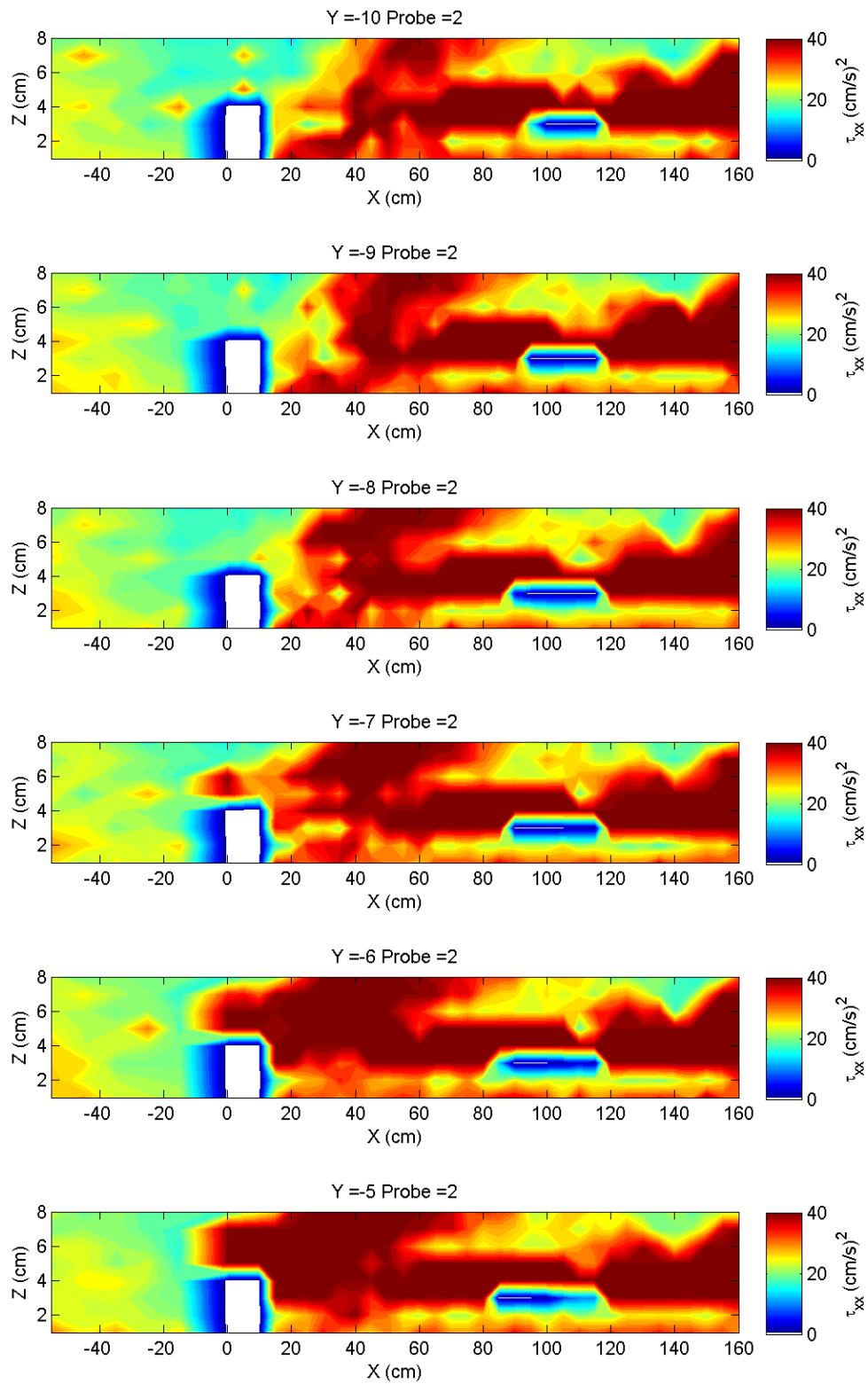


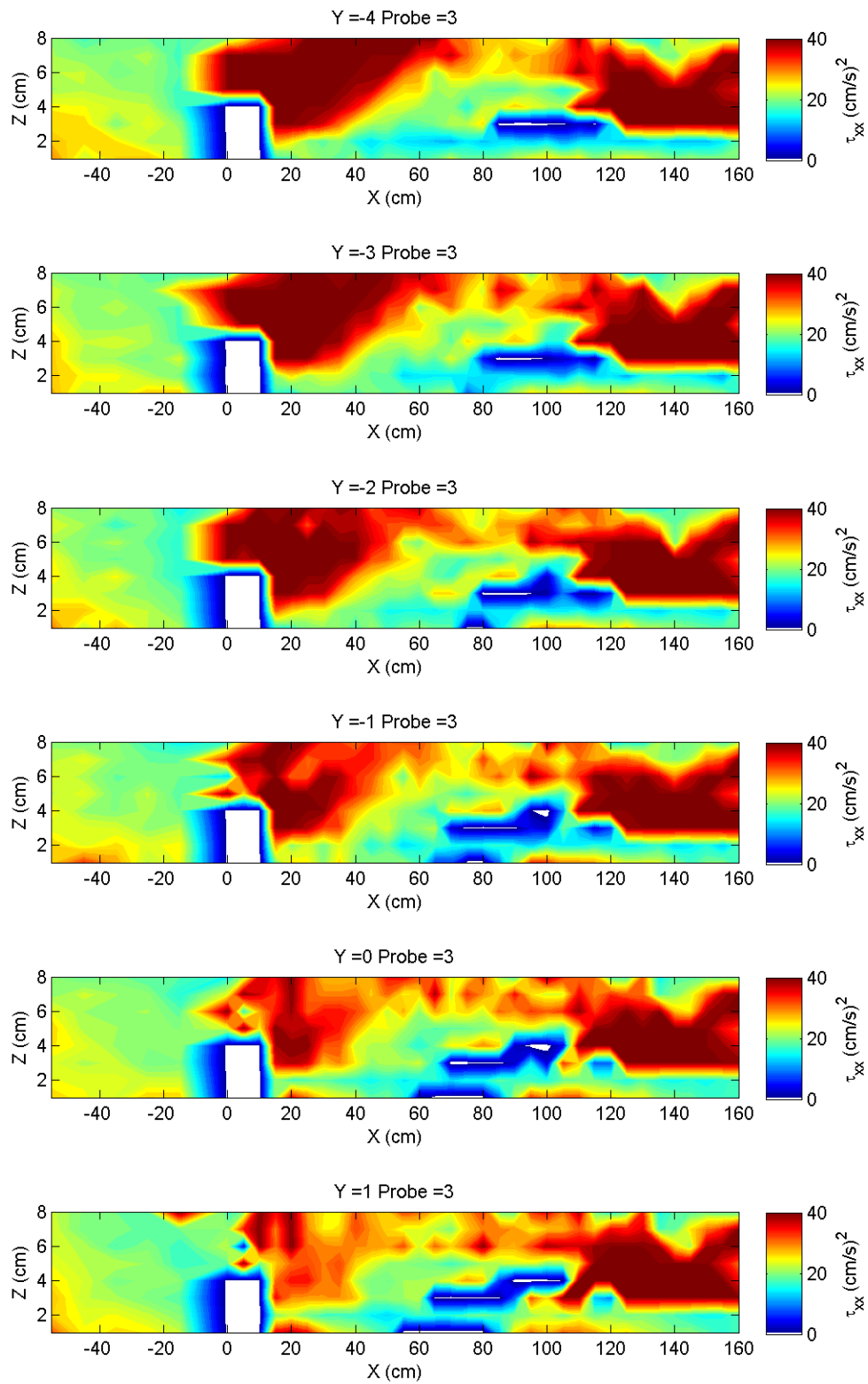


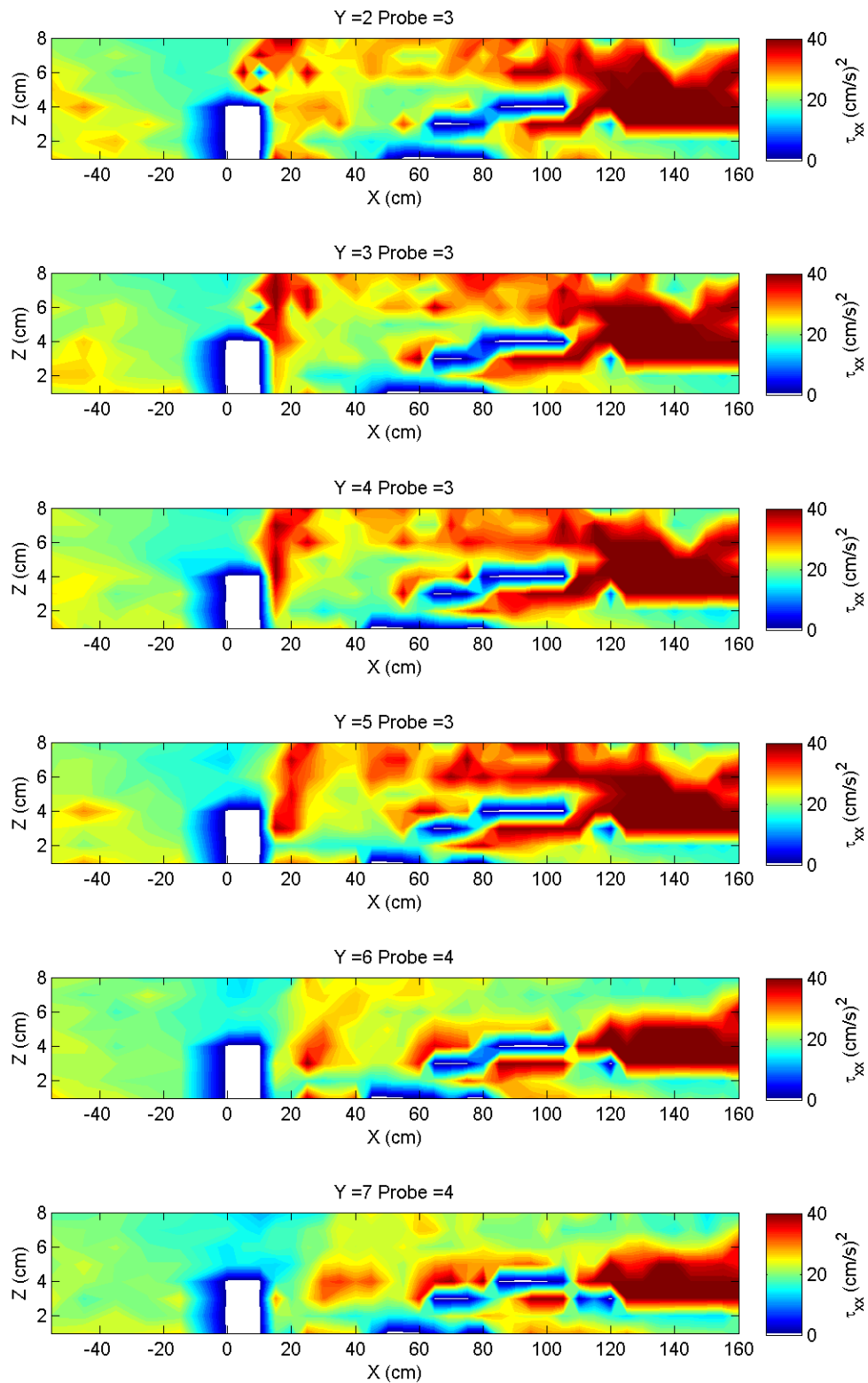


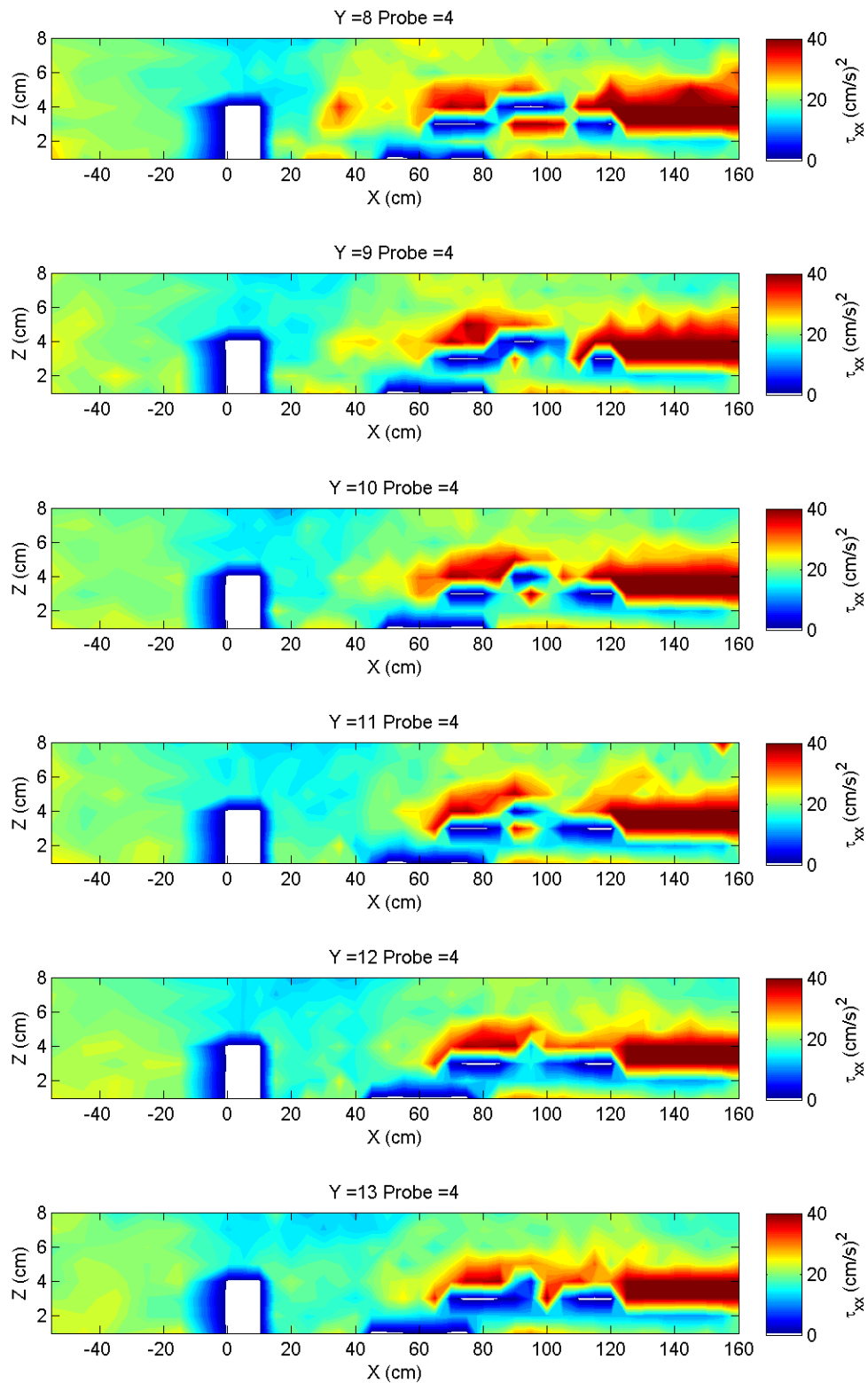


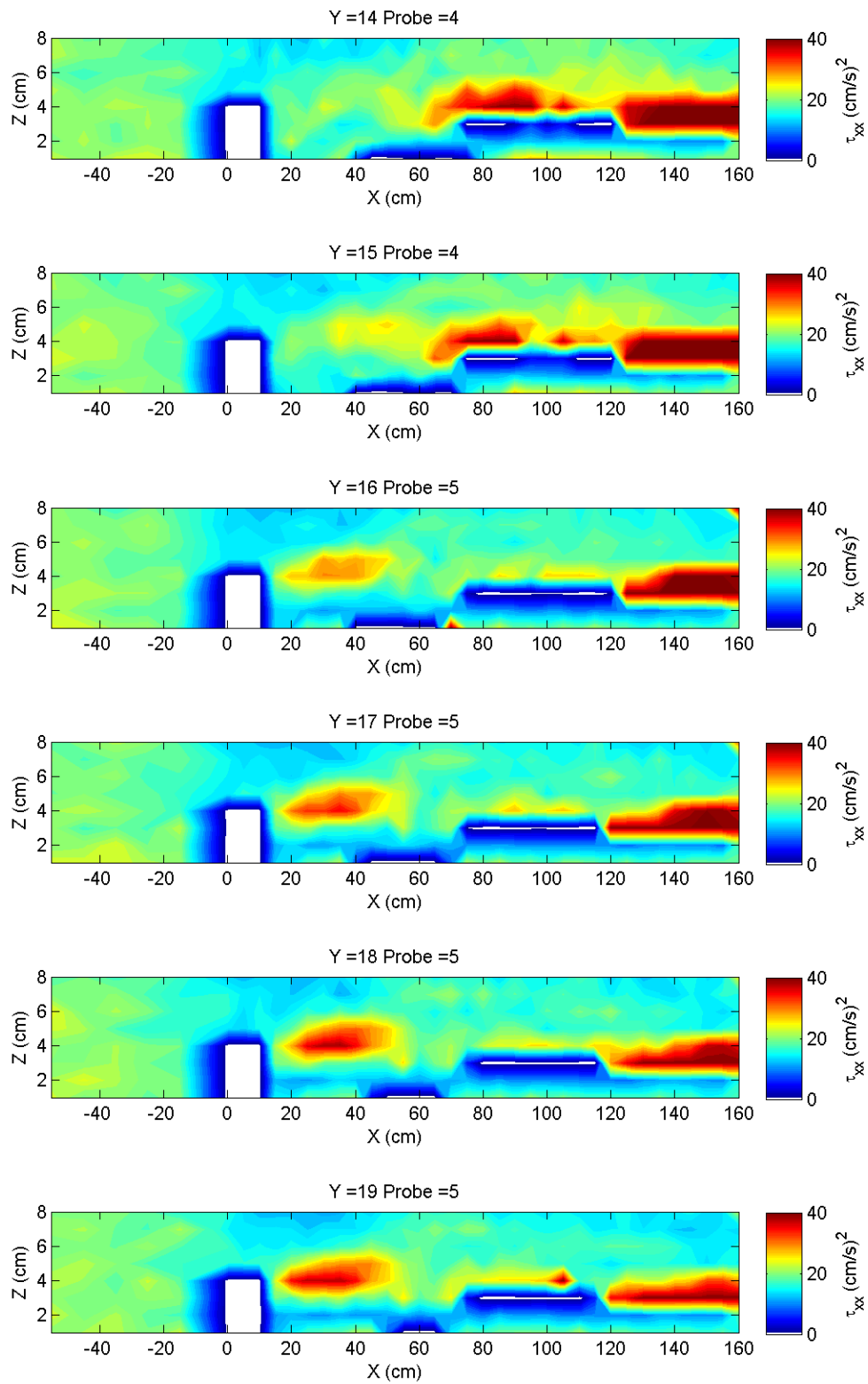




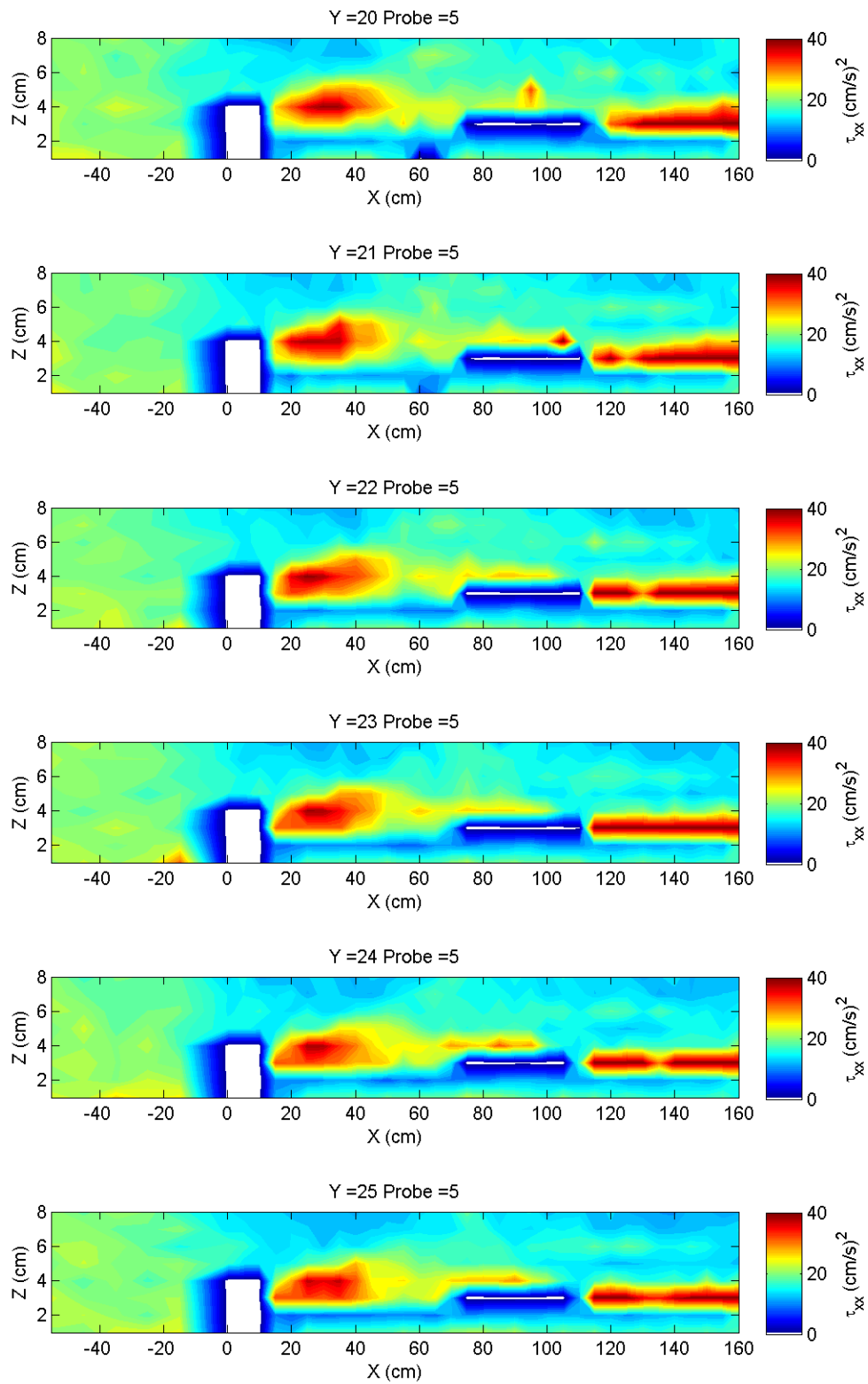


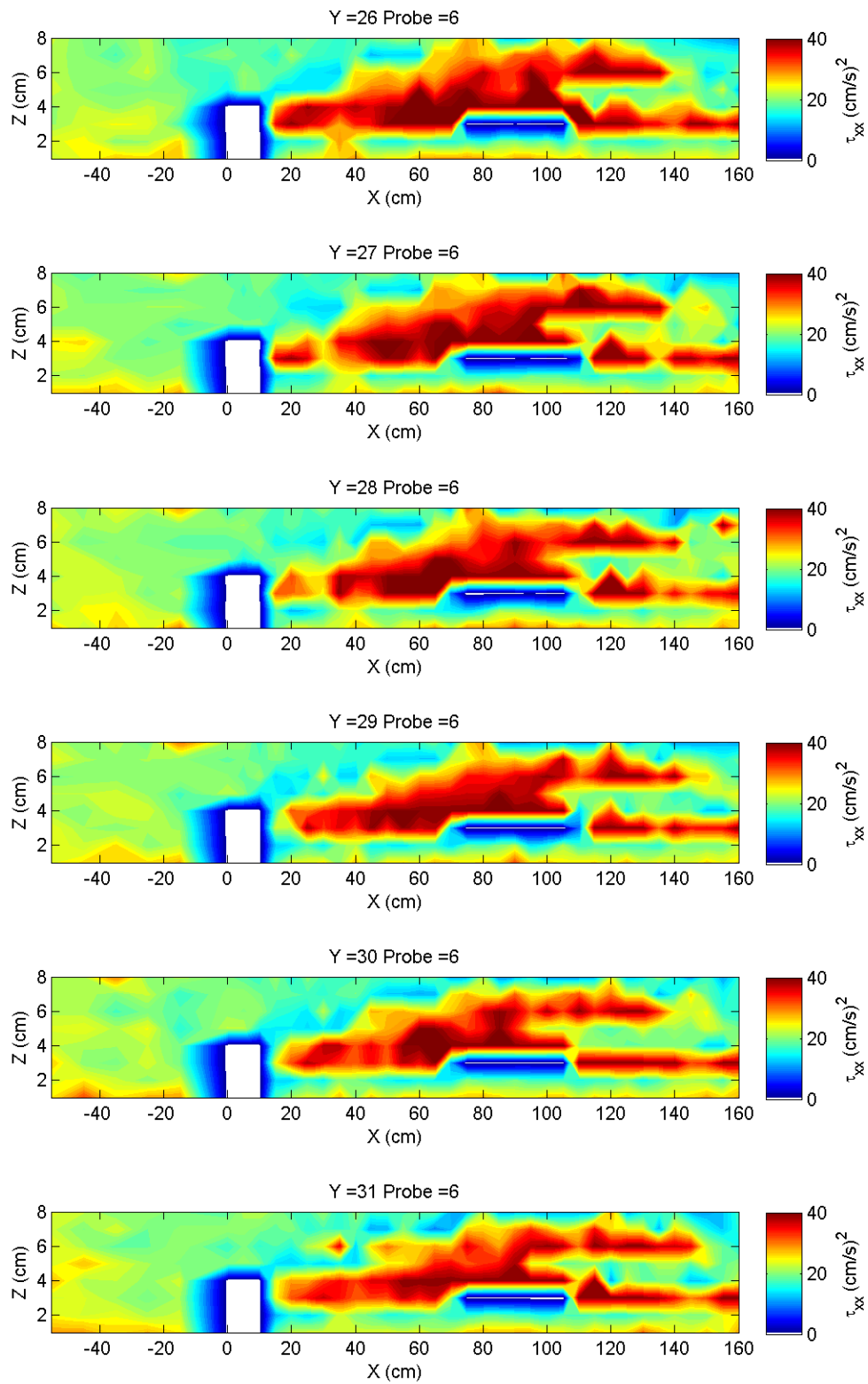


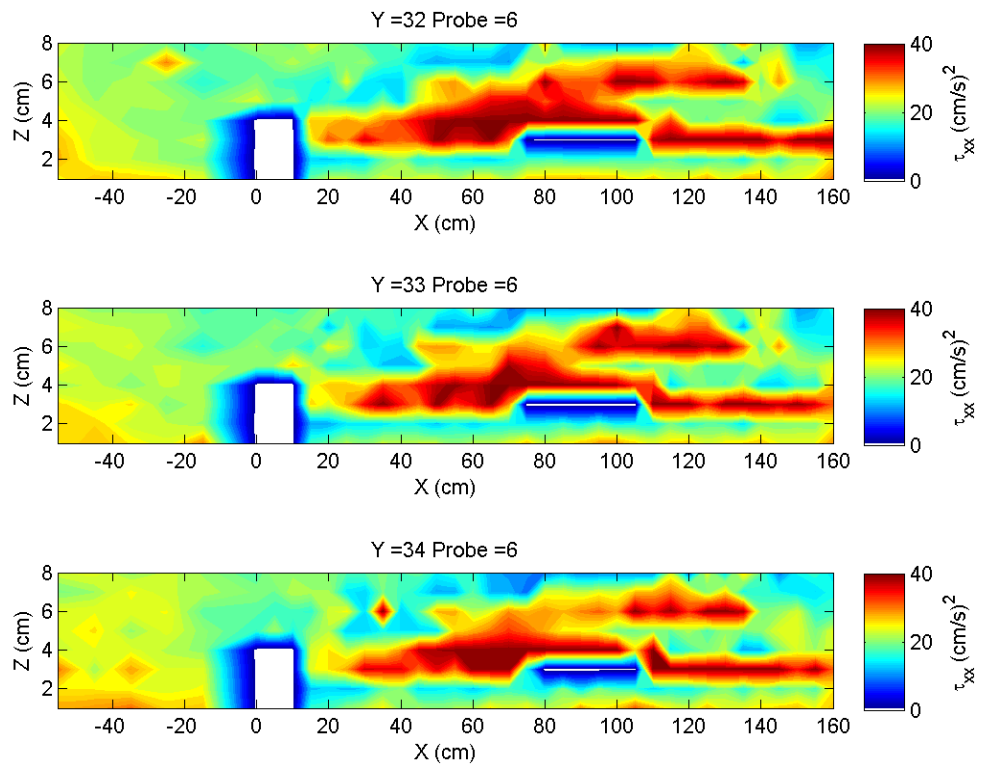




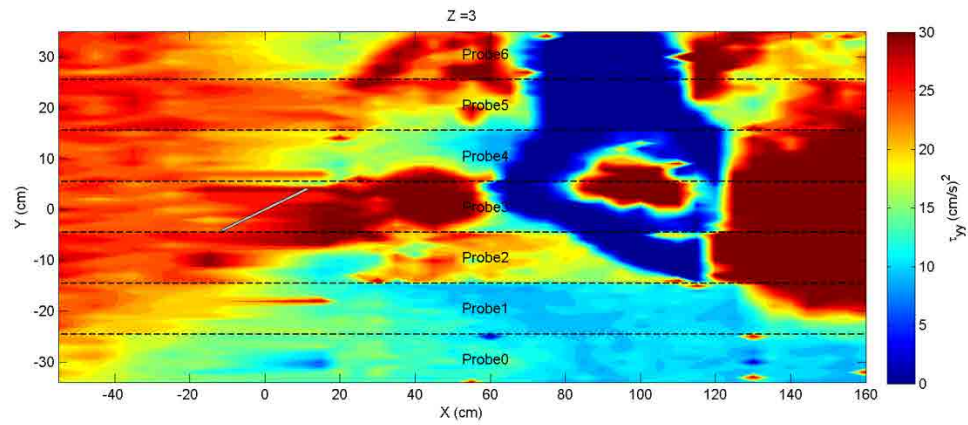
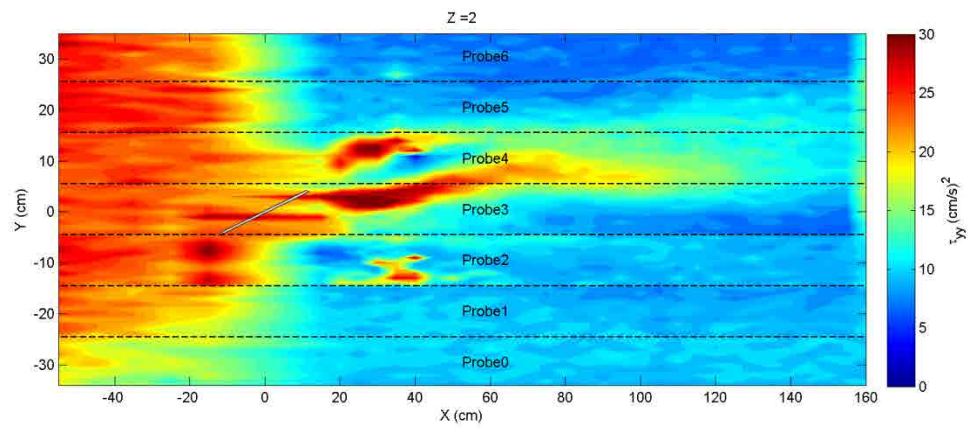
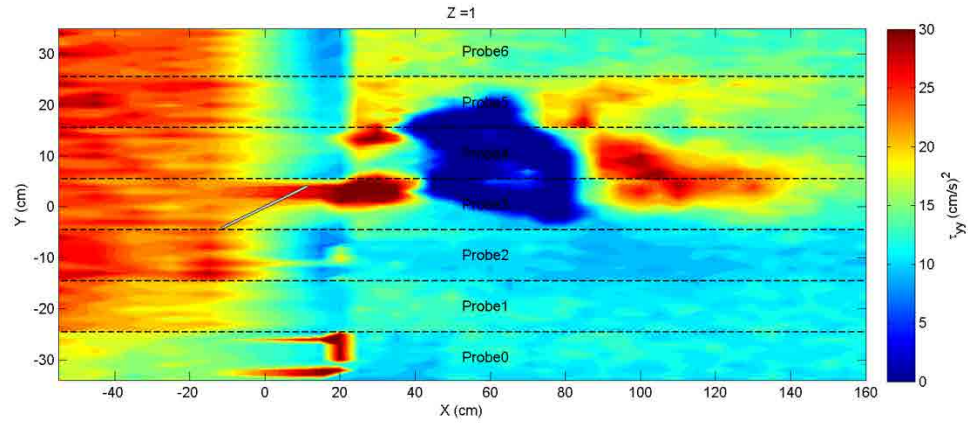


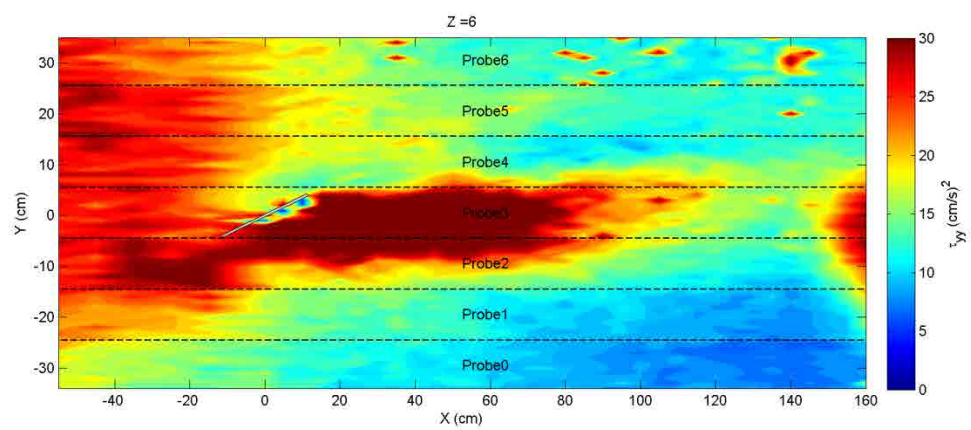
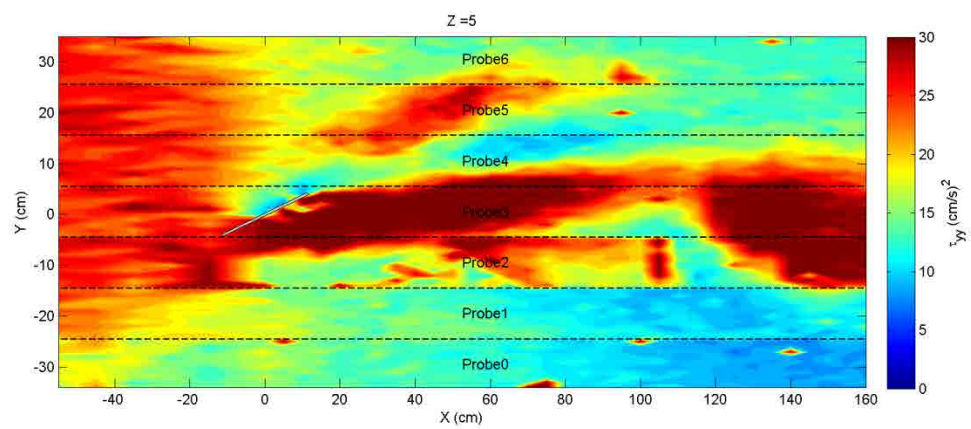
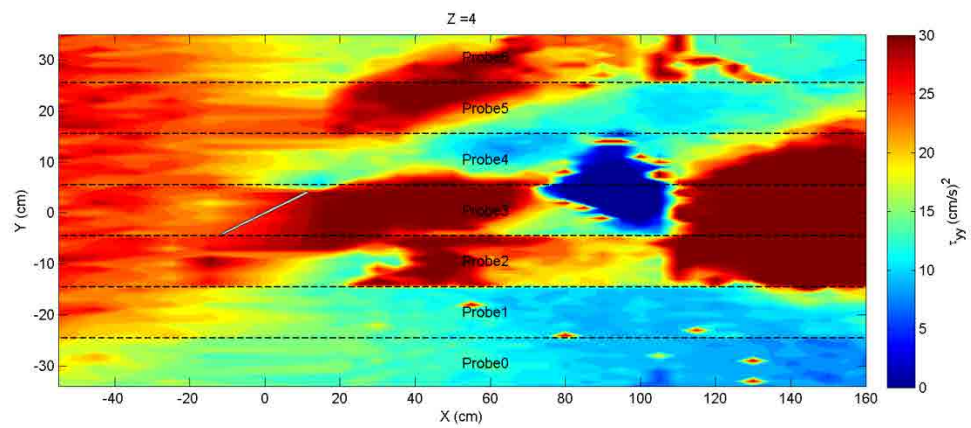




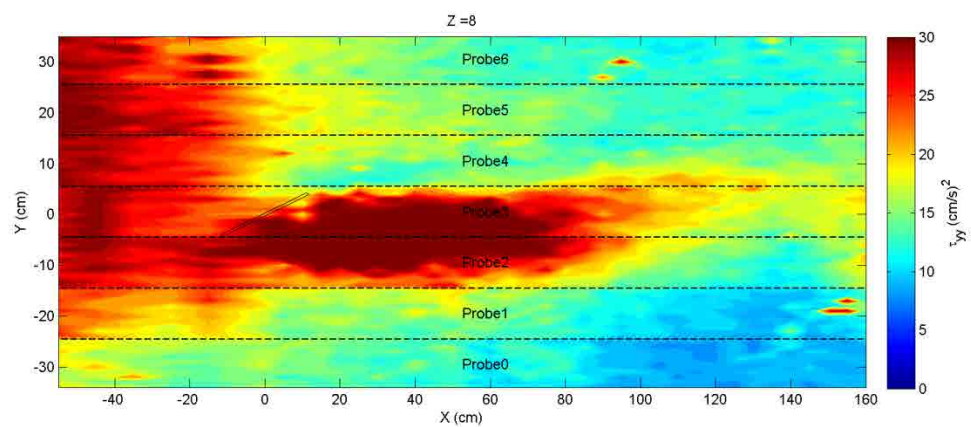
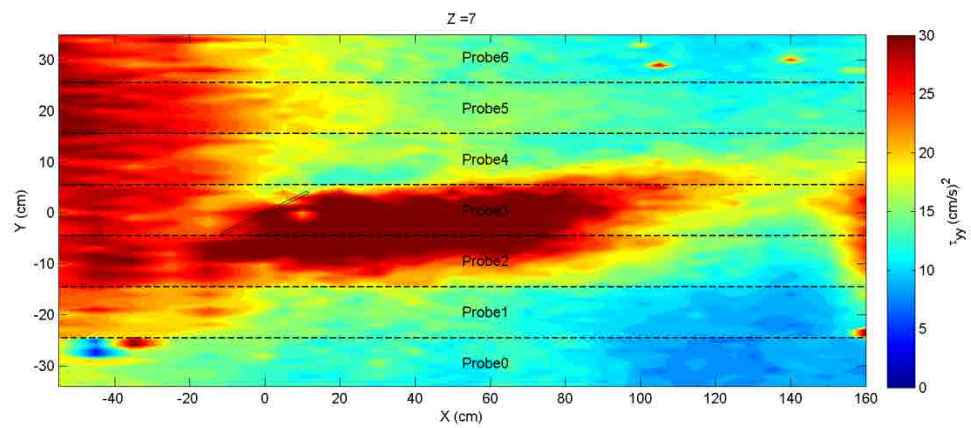


#### 4. Reynolds Normal Stresses $\tau_{yy}$ in x and y-Directions

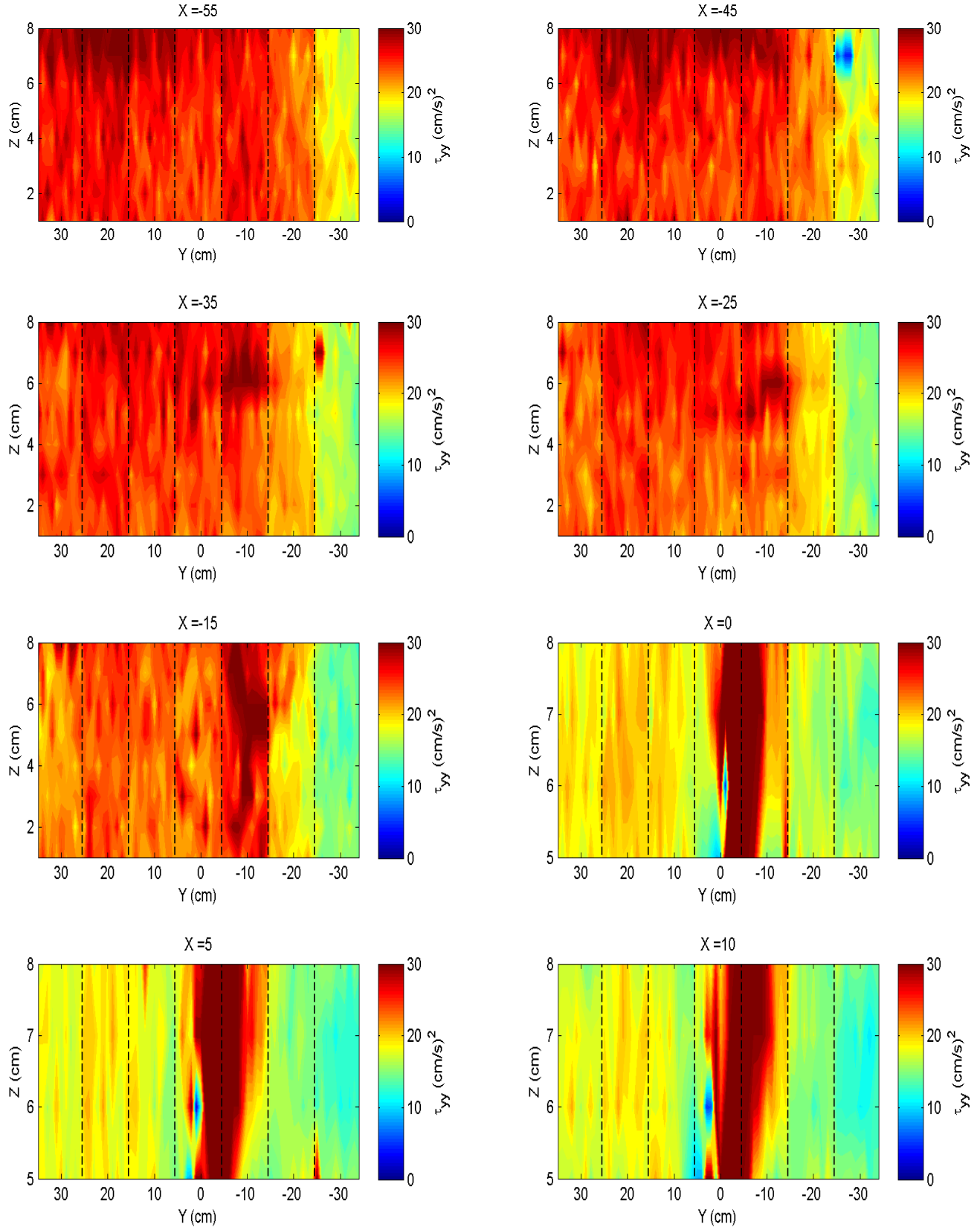


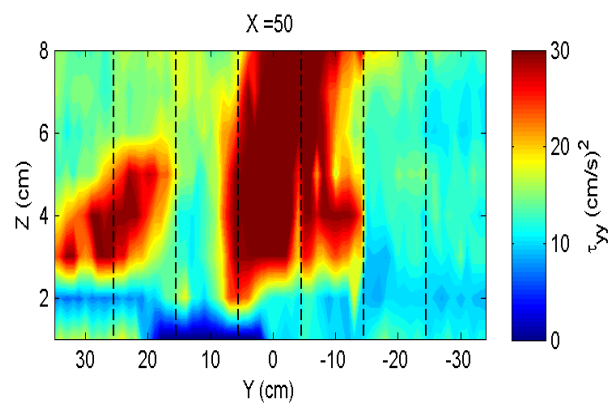
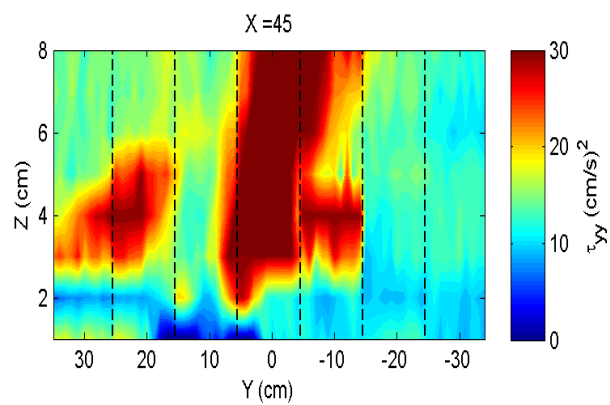
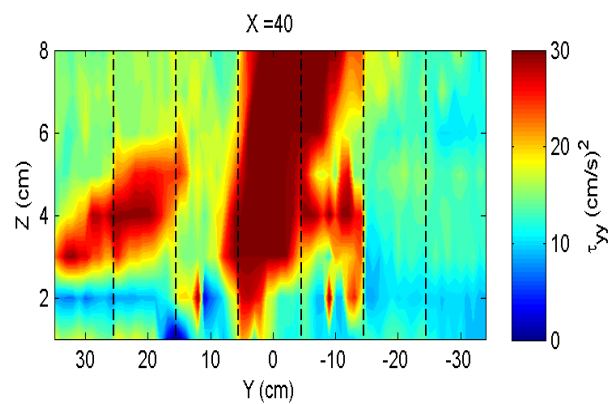
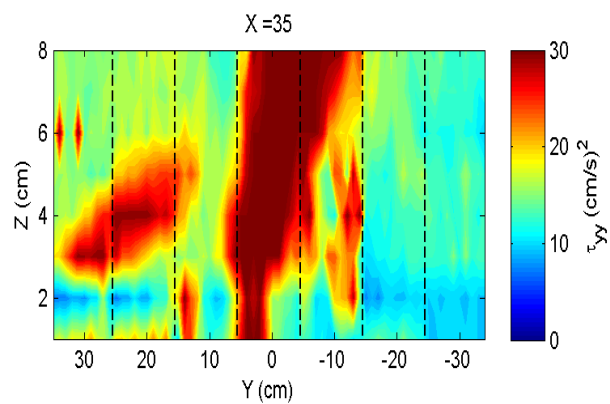
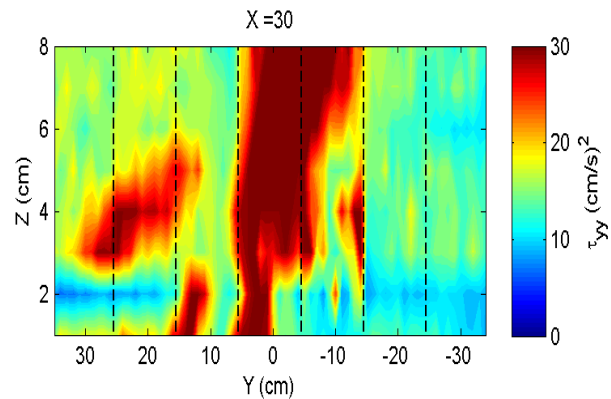
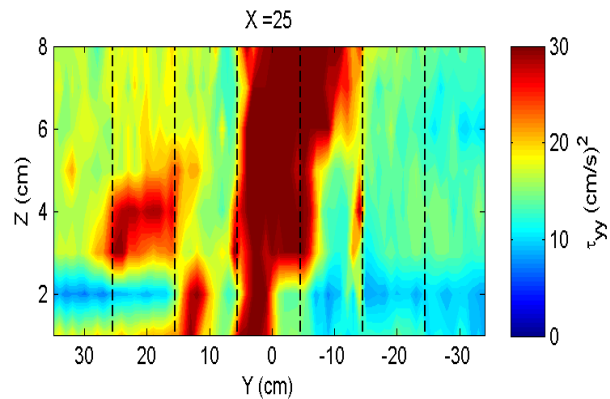
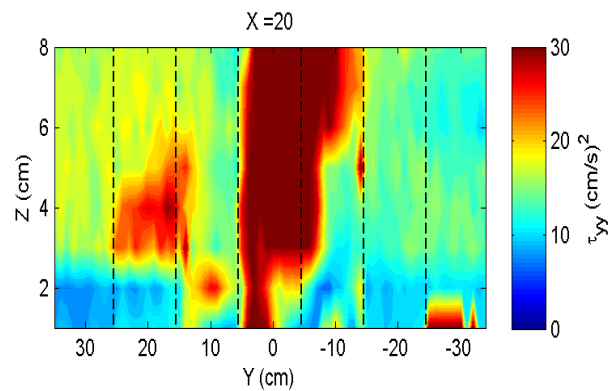
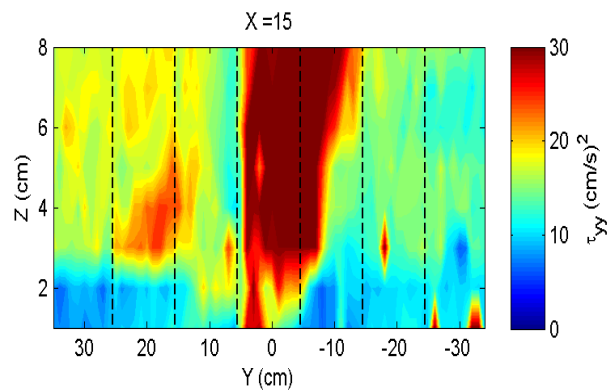




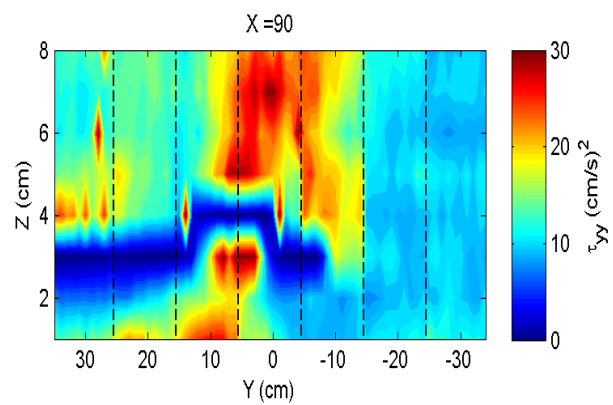
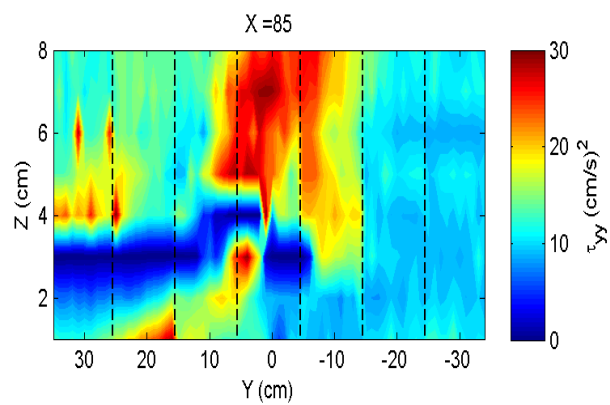
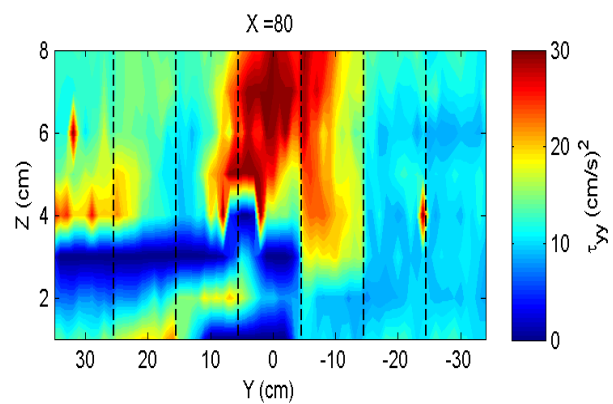
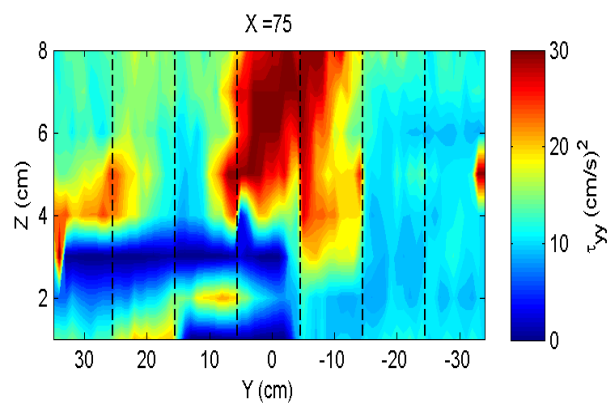
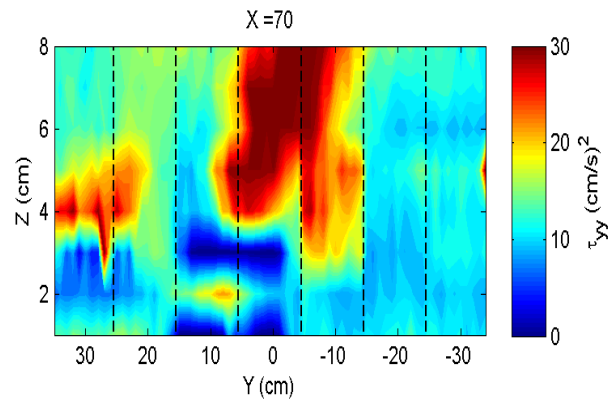
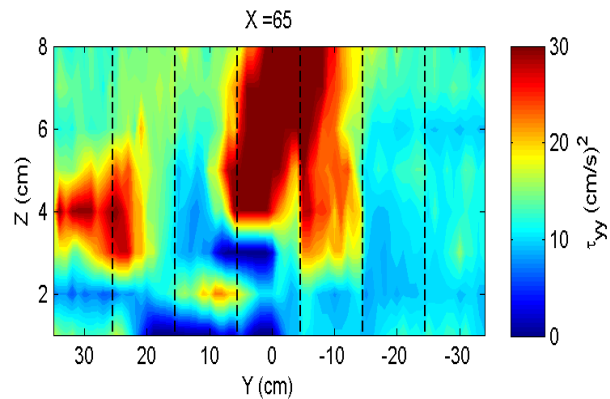
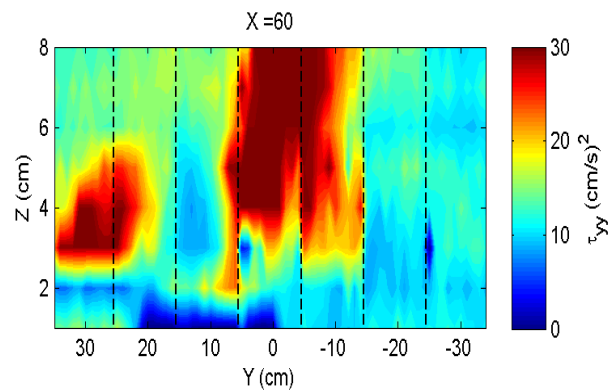
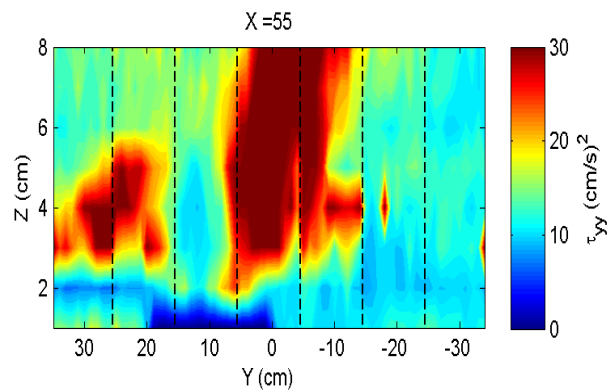


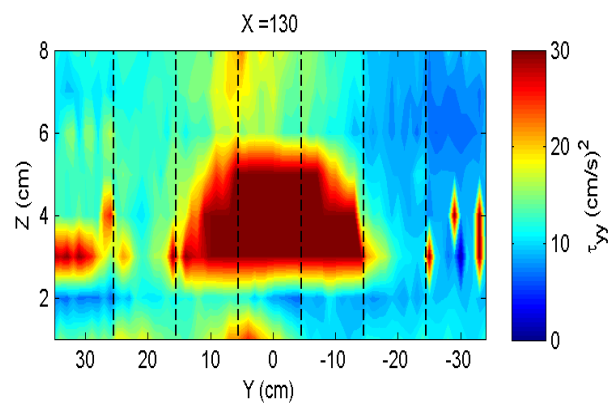
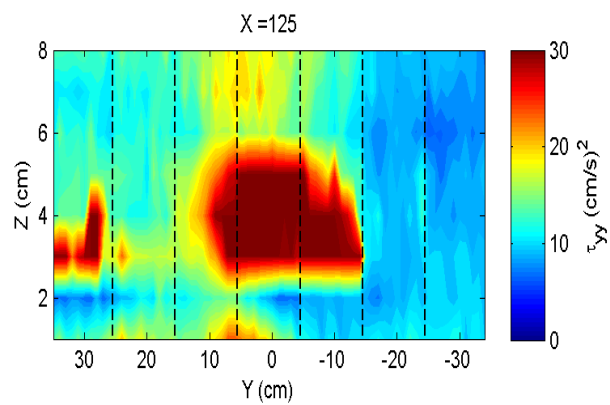
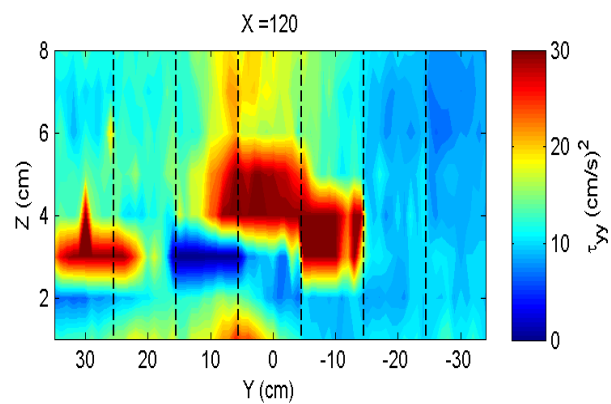
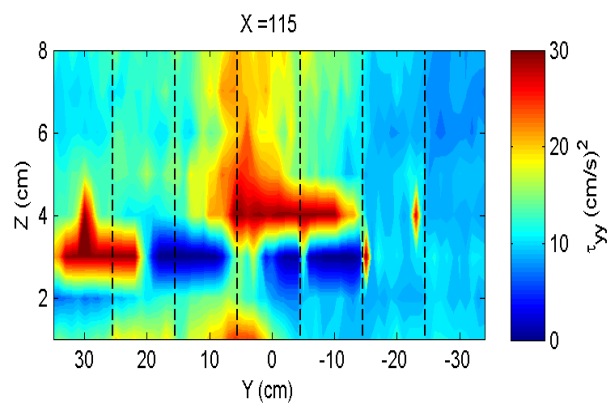
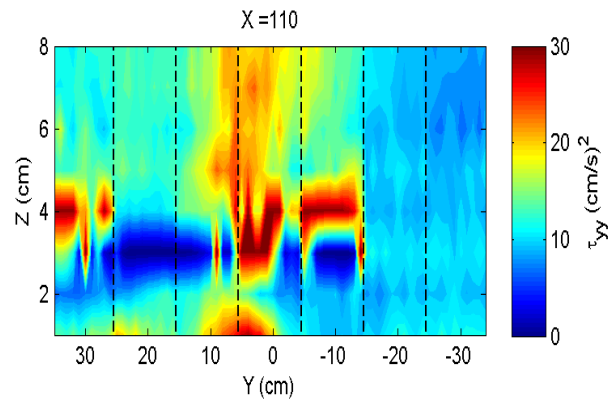
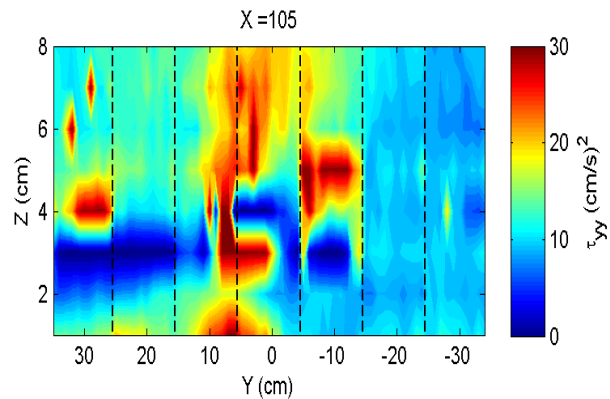
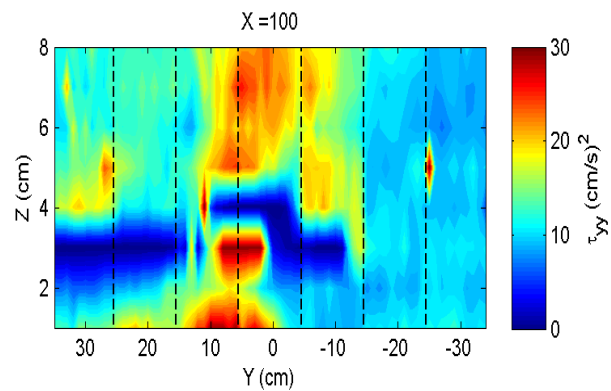
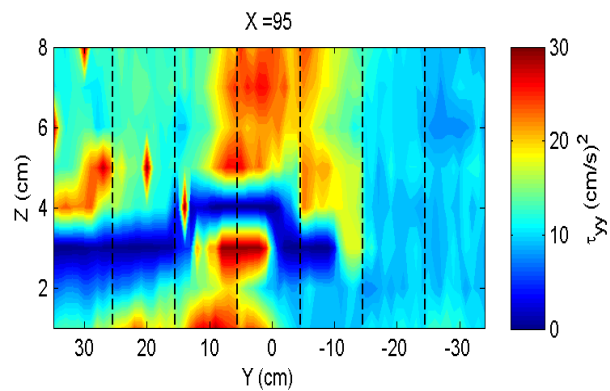
## 5. Reynolds Normal Stresses $\tau_{yy}$ in y and z-Directions

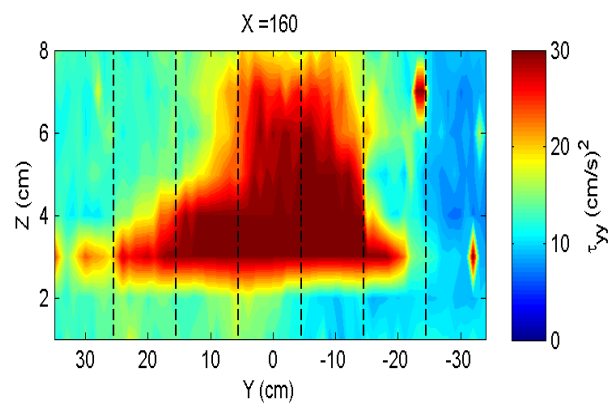
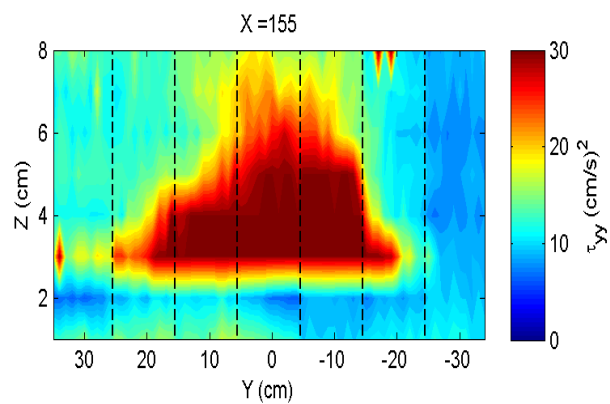
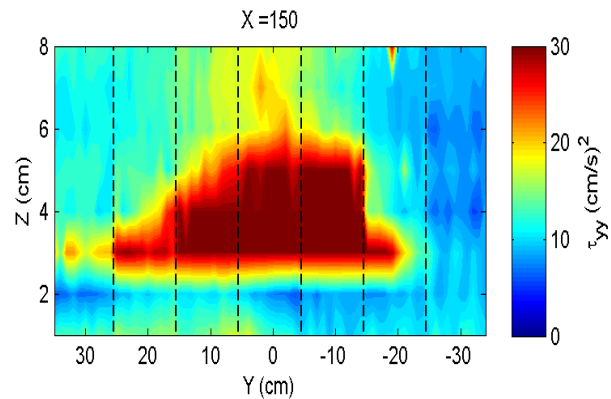
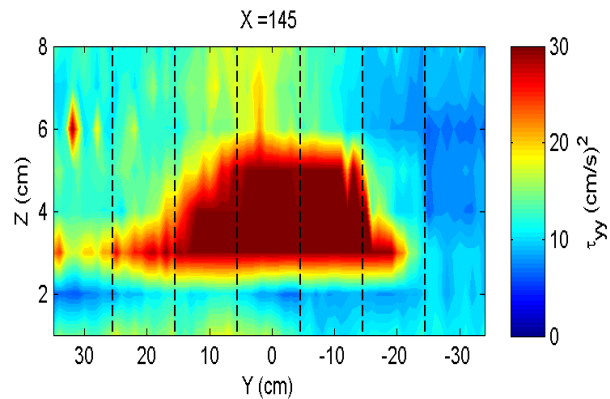
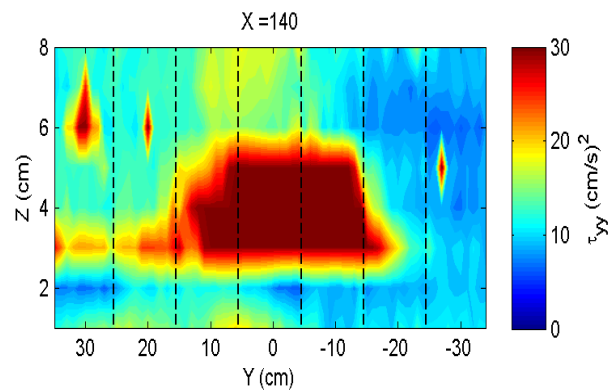
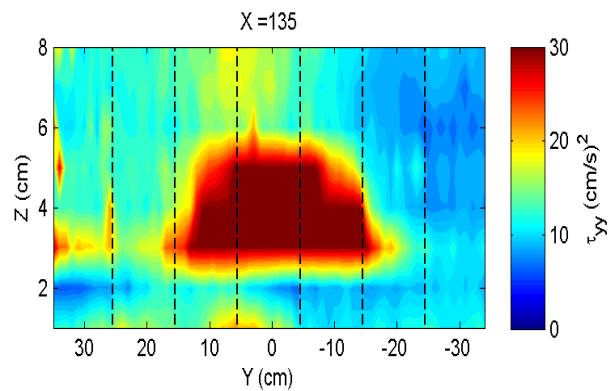




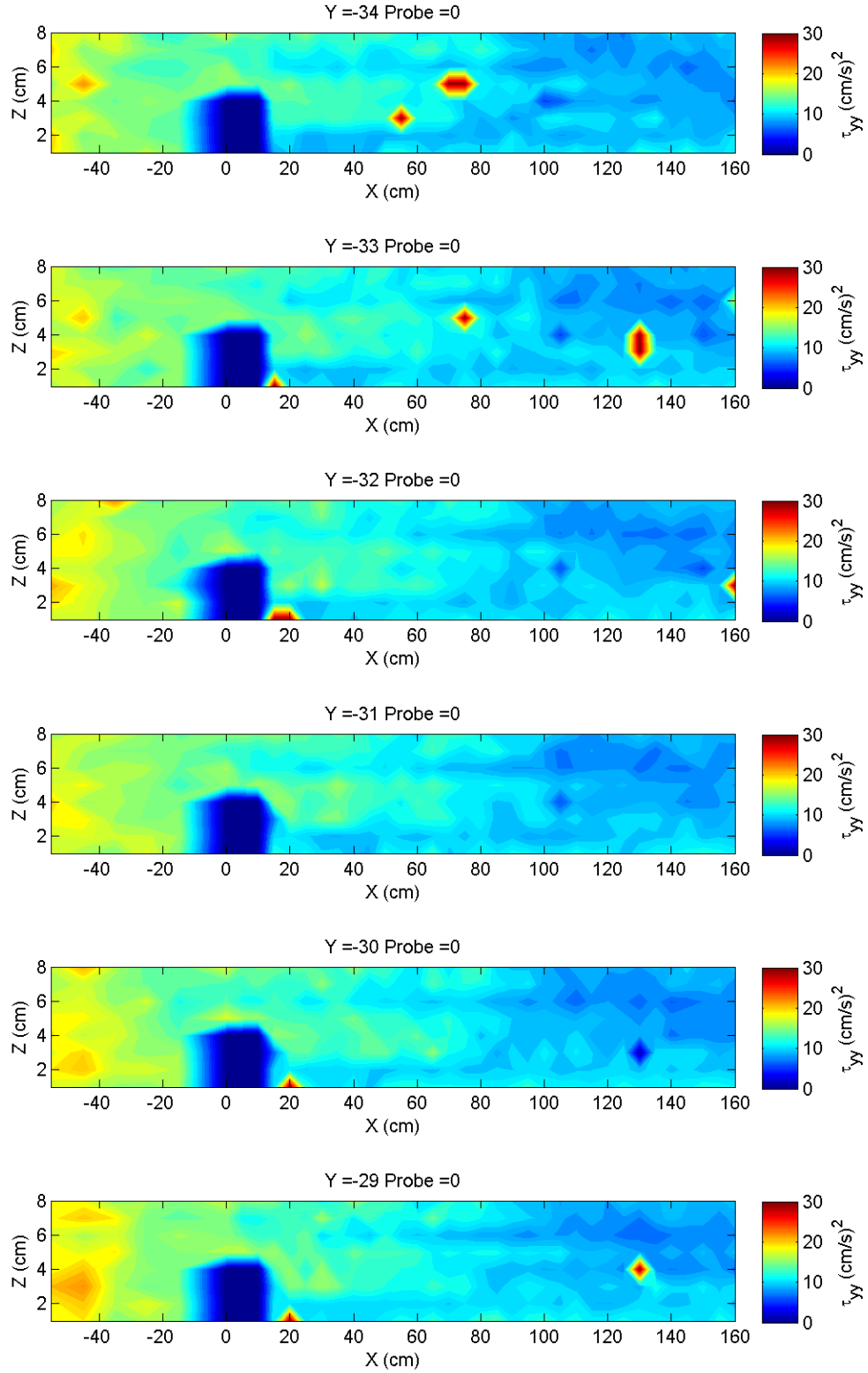


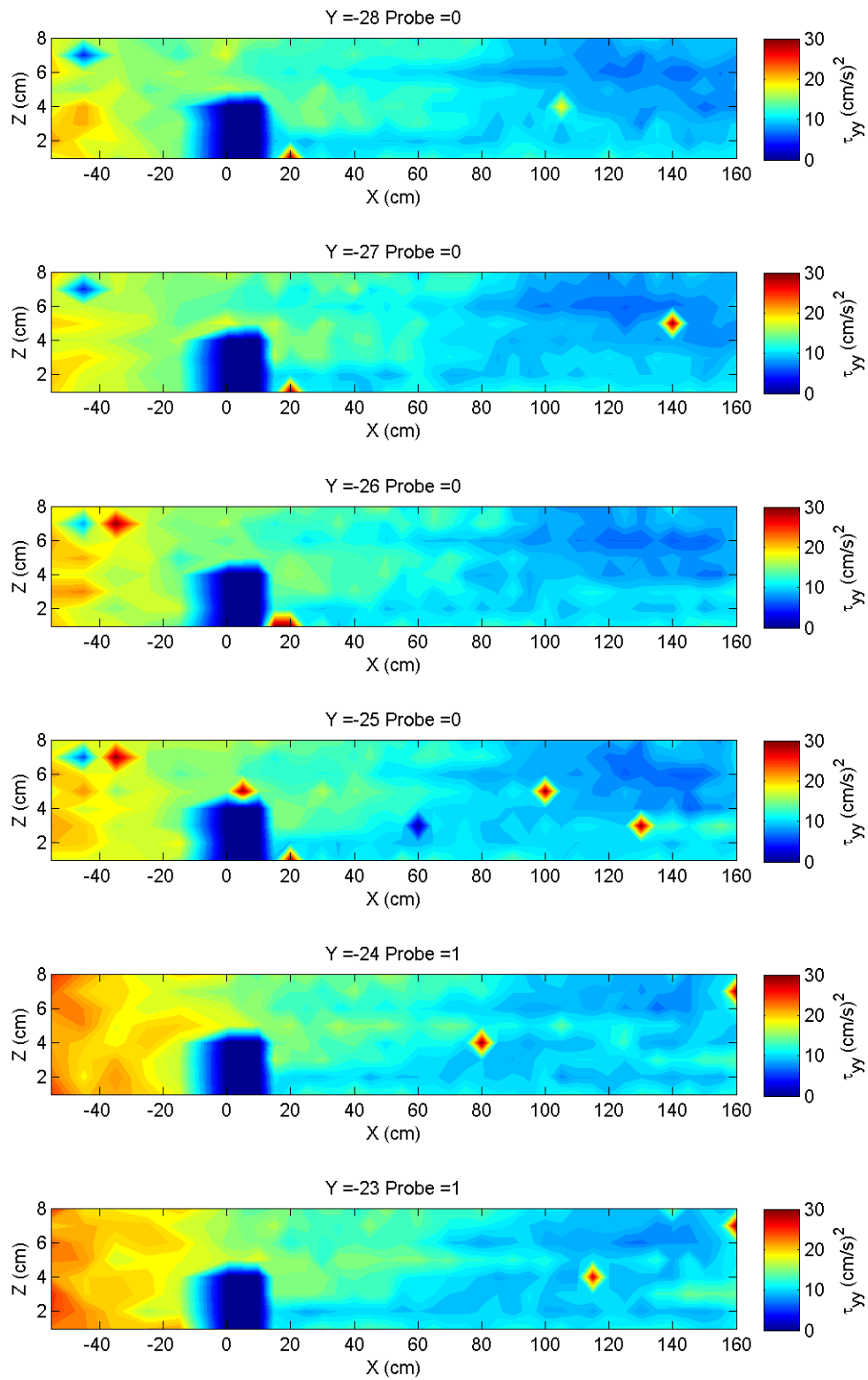


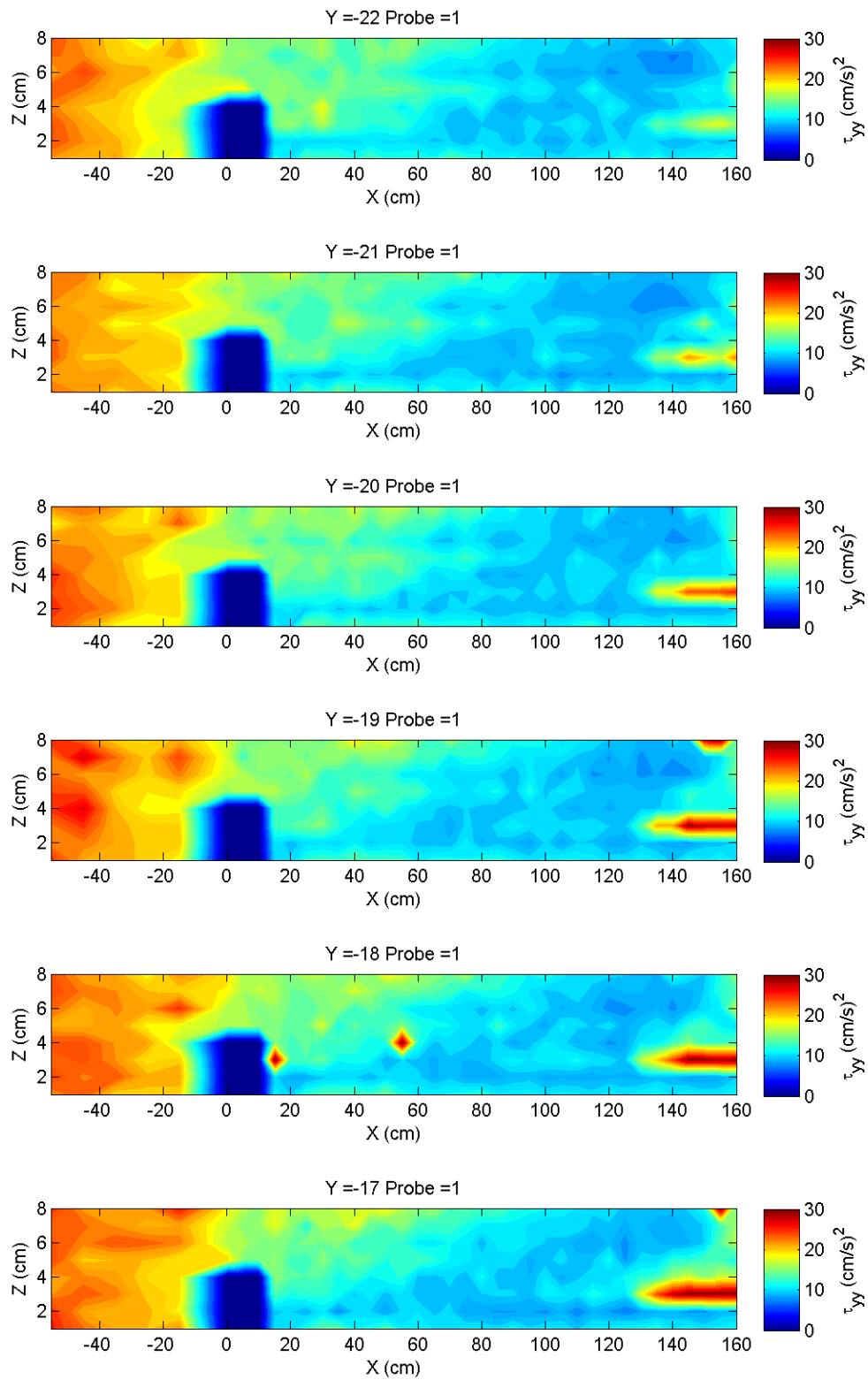


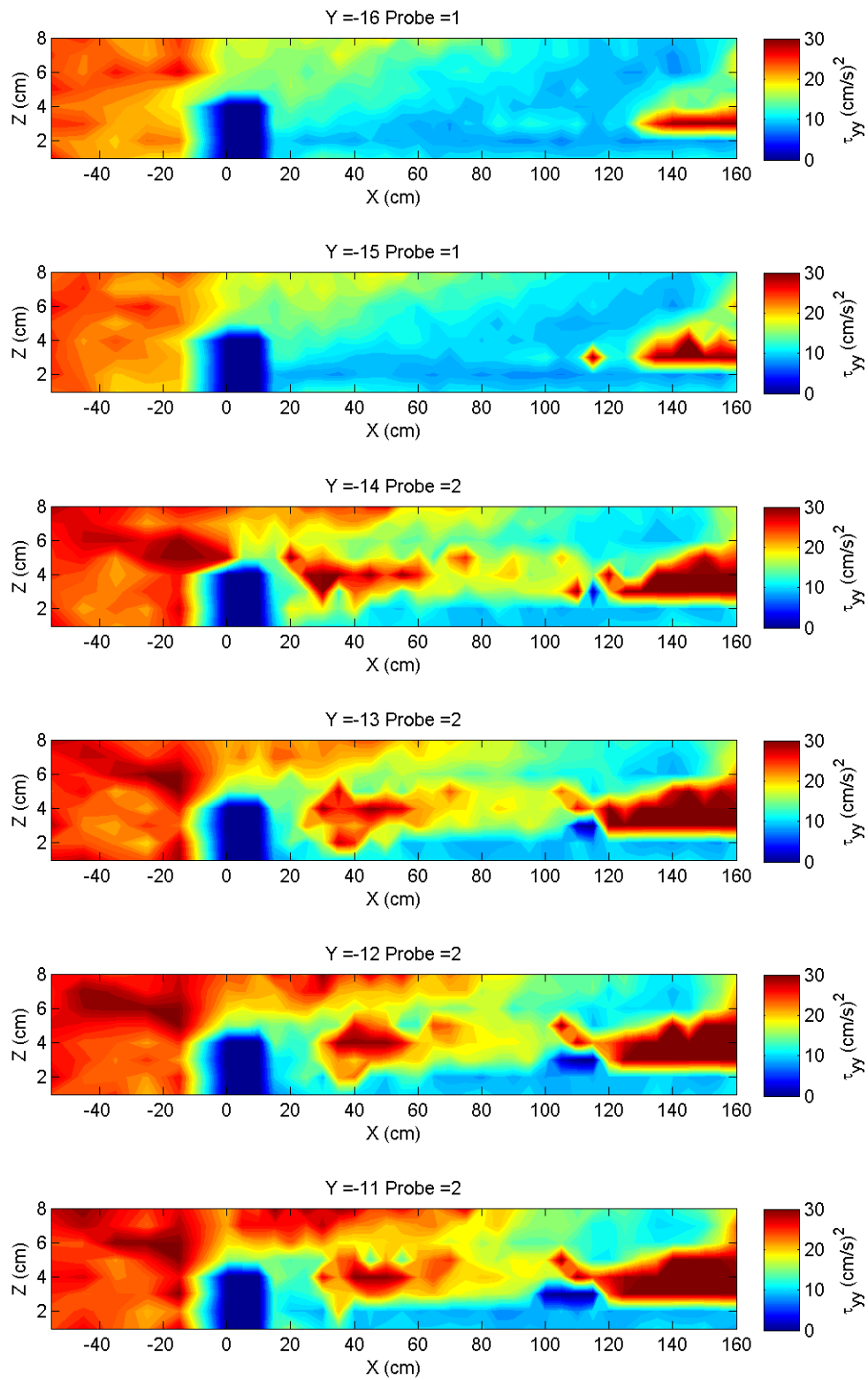


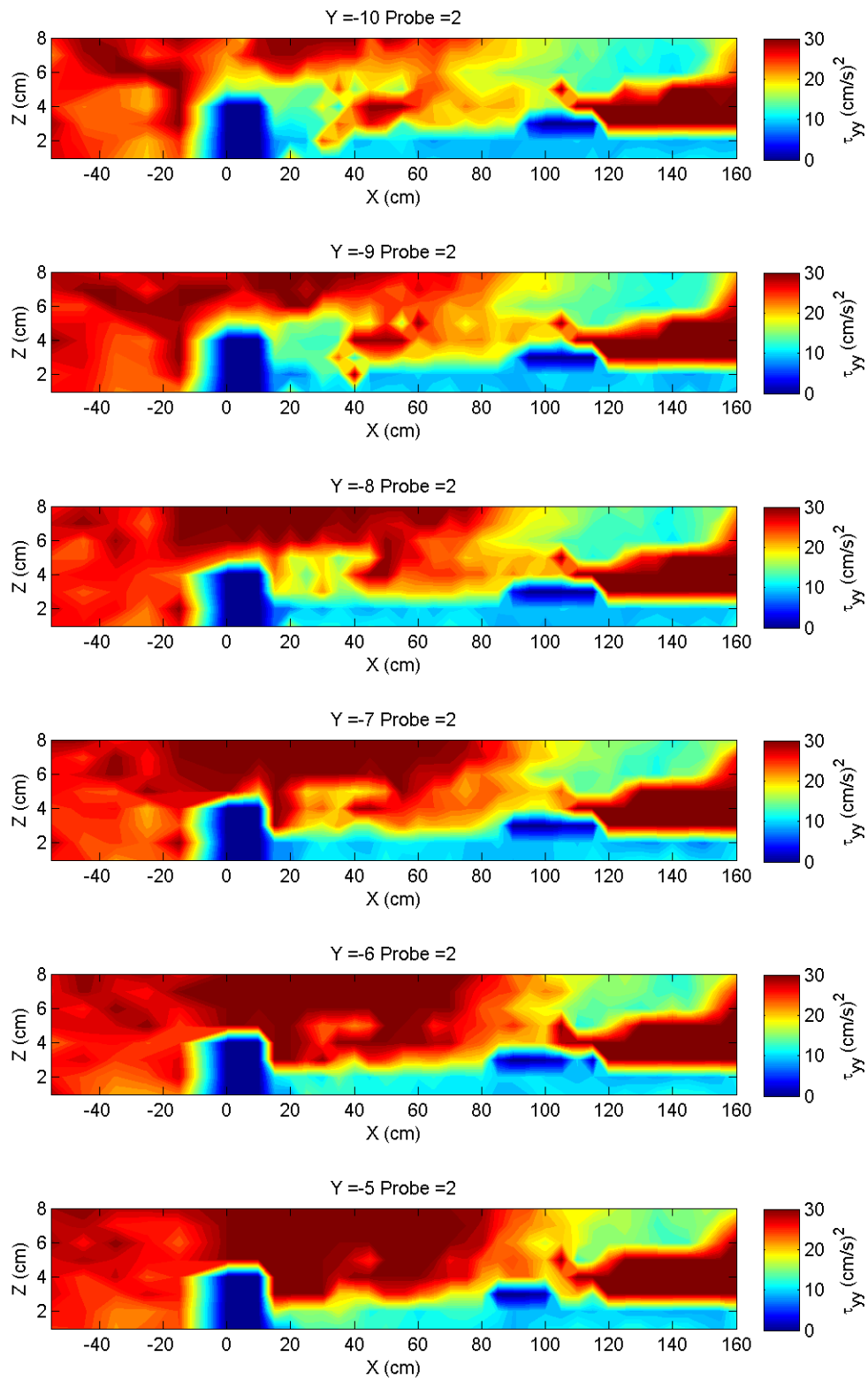
## 6. Reynolds Normal Stresses $\tau_{yy}$ in x and z-Directions



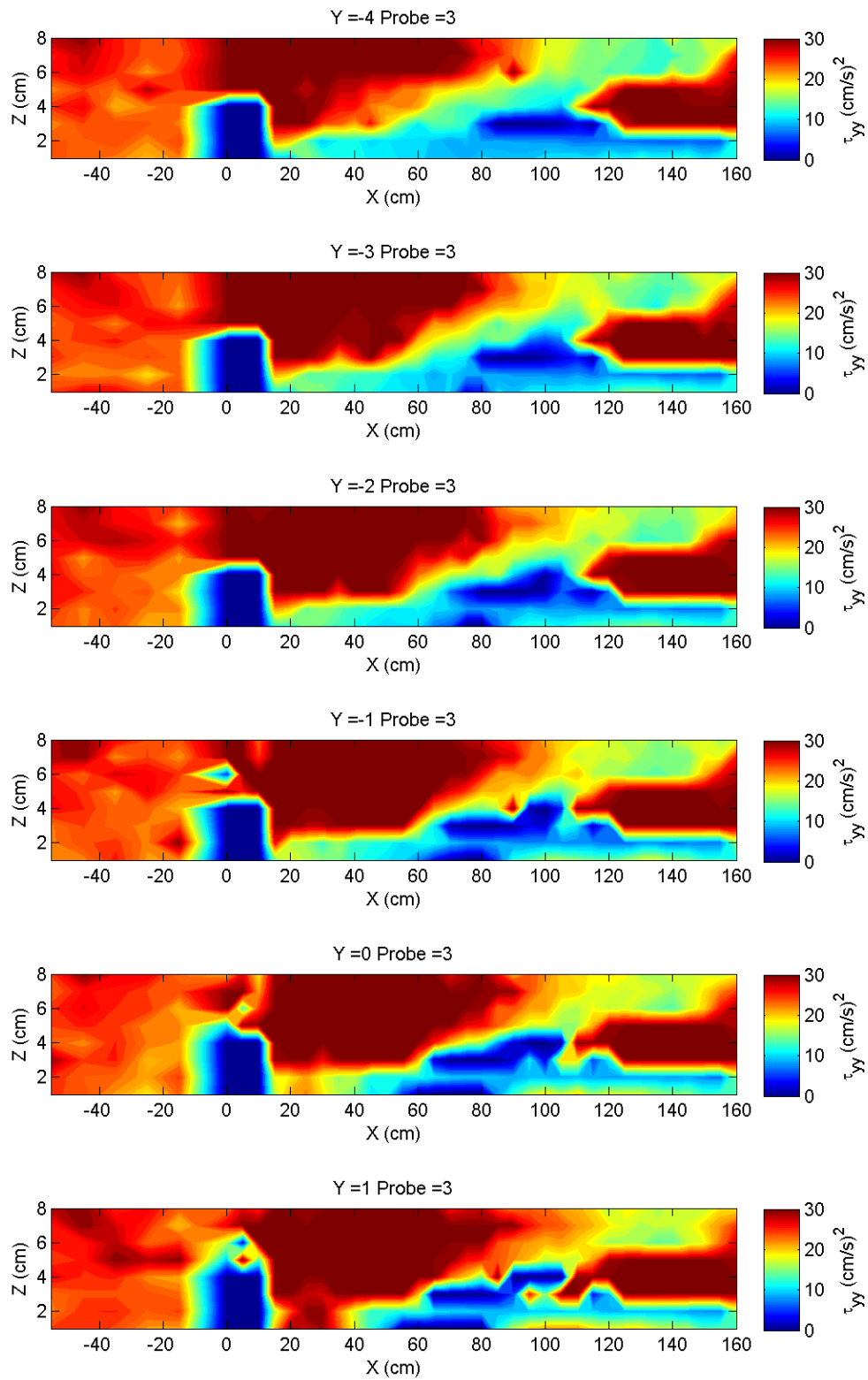


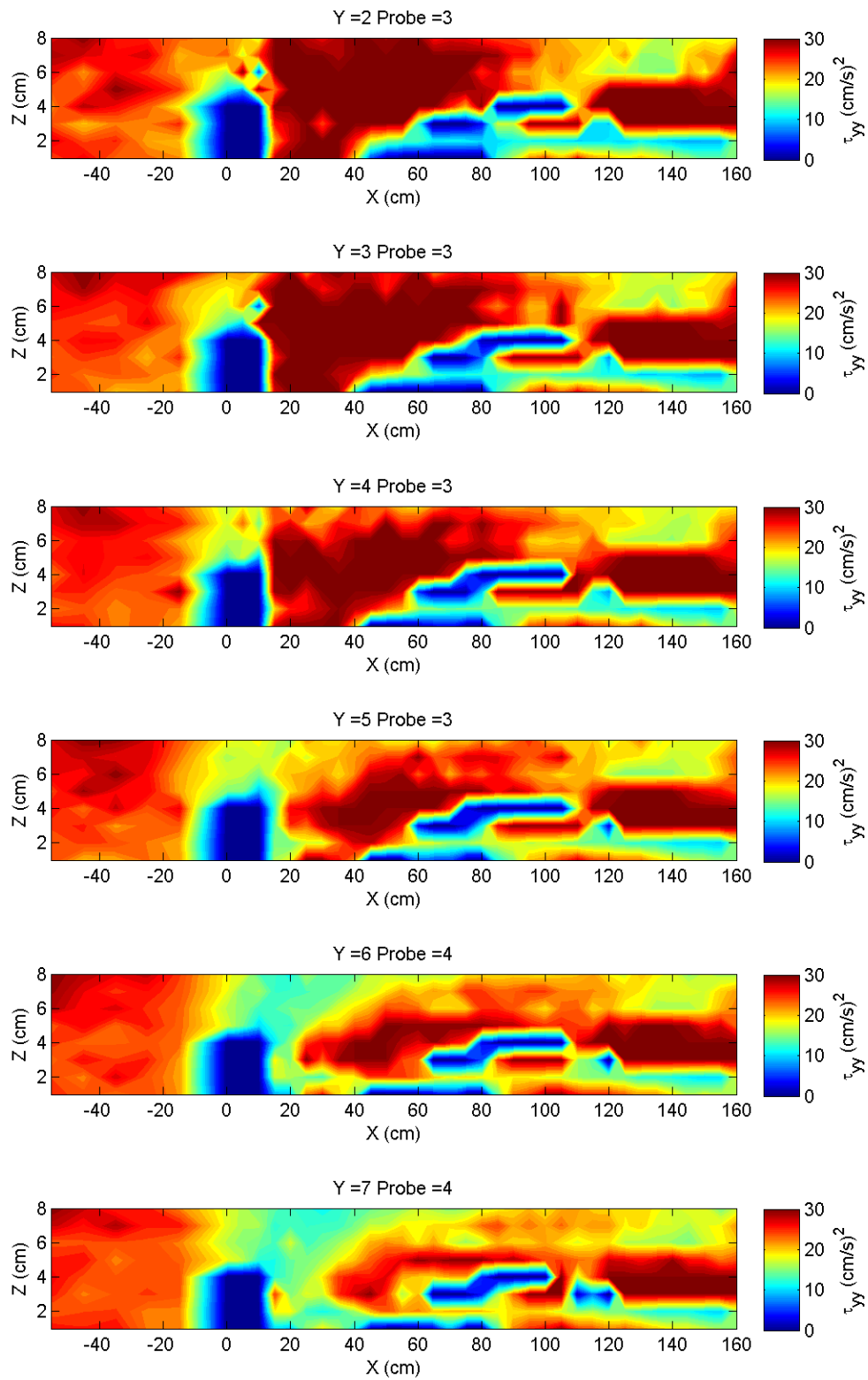


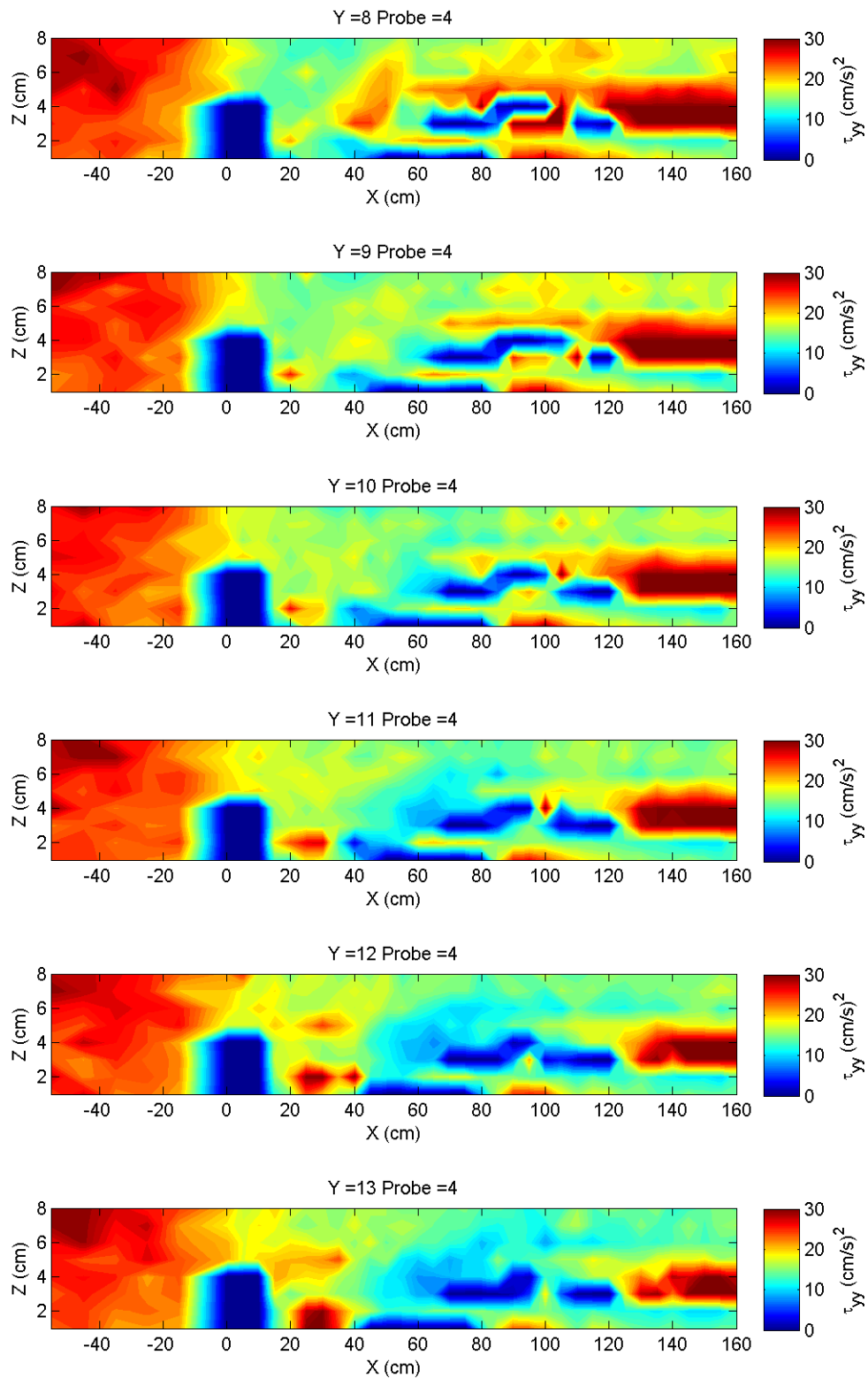


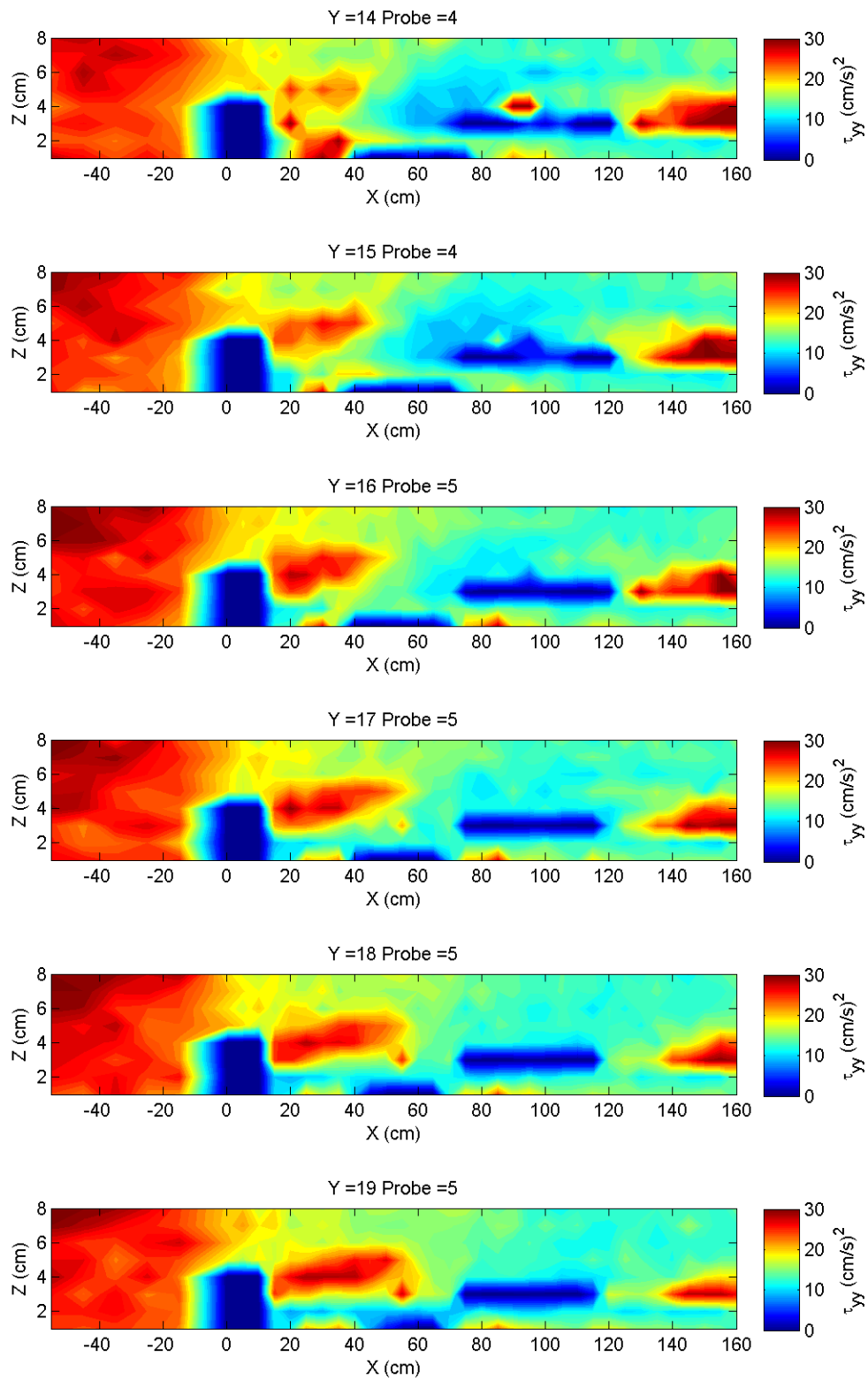


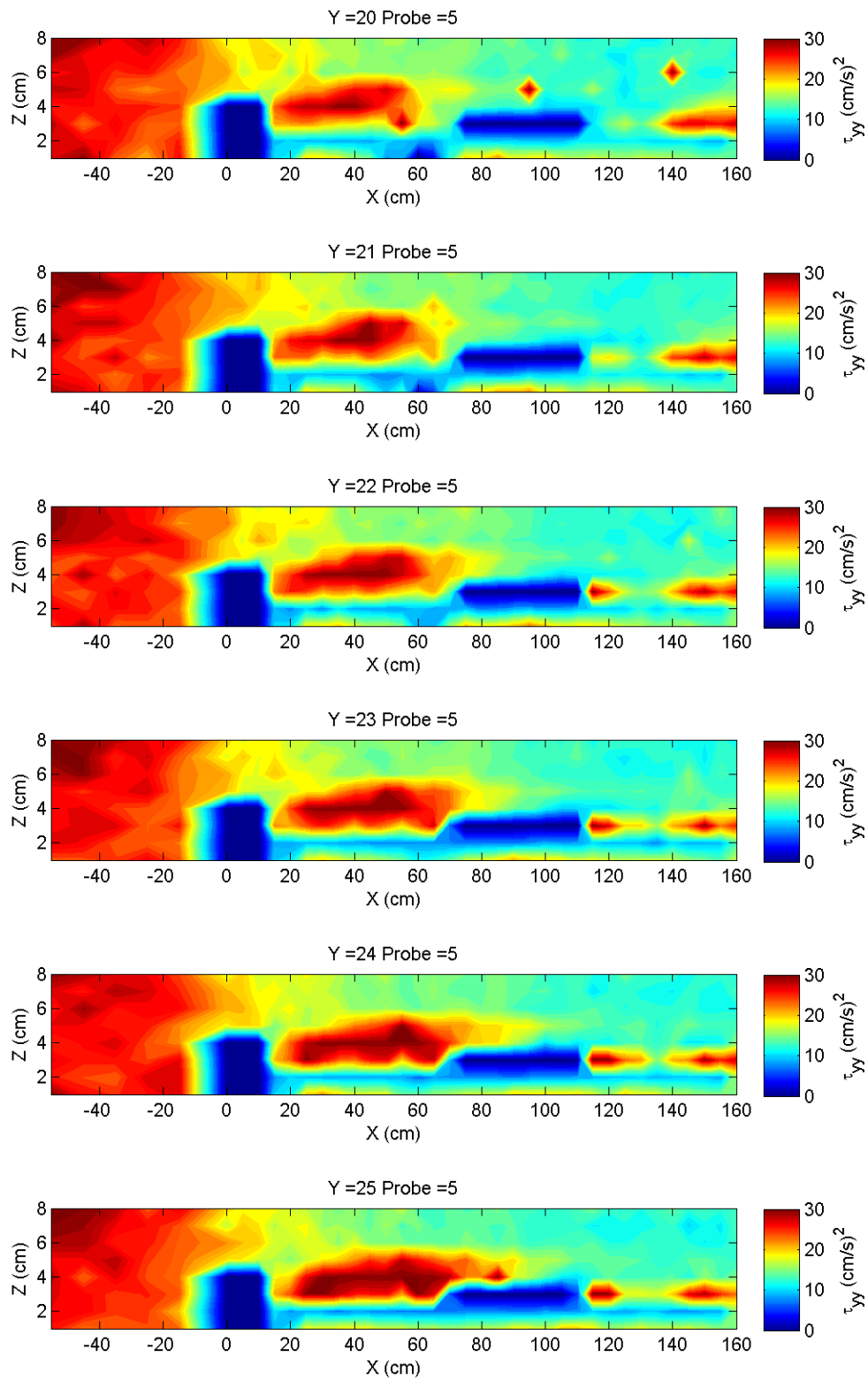


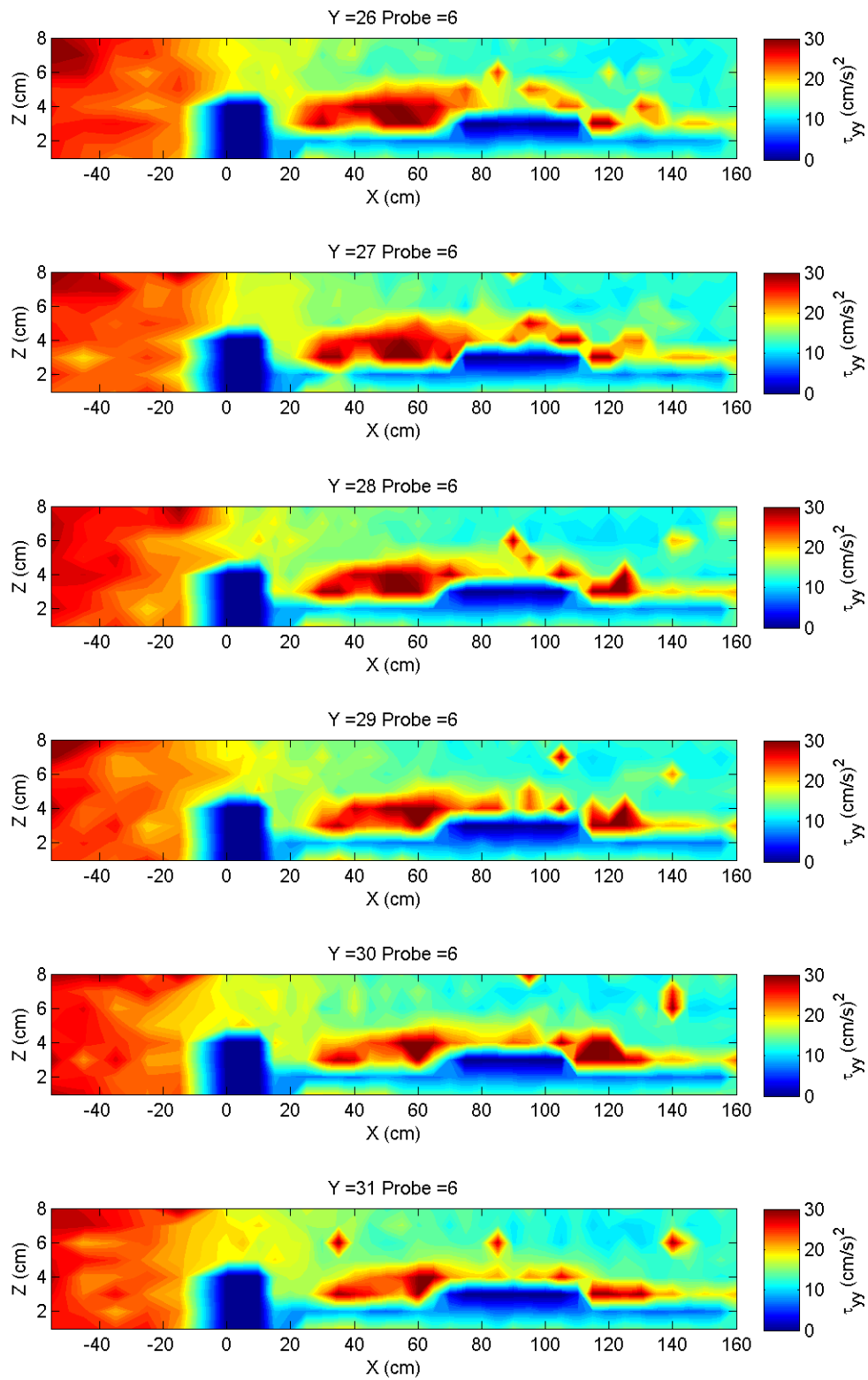


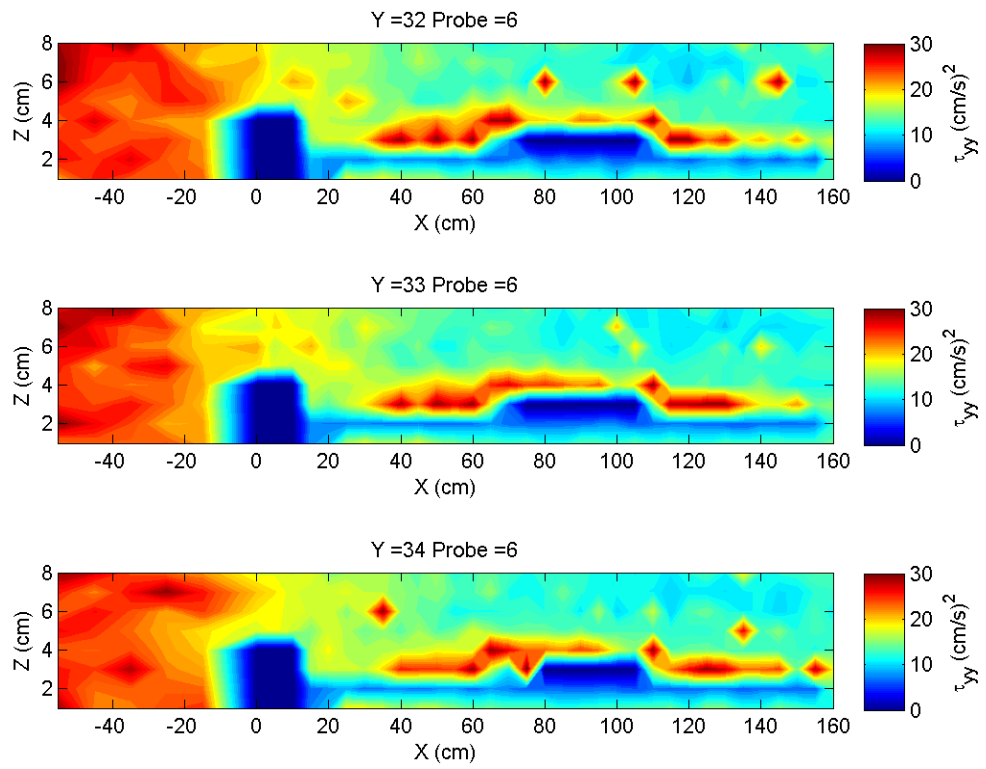




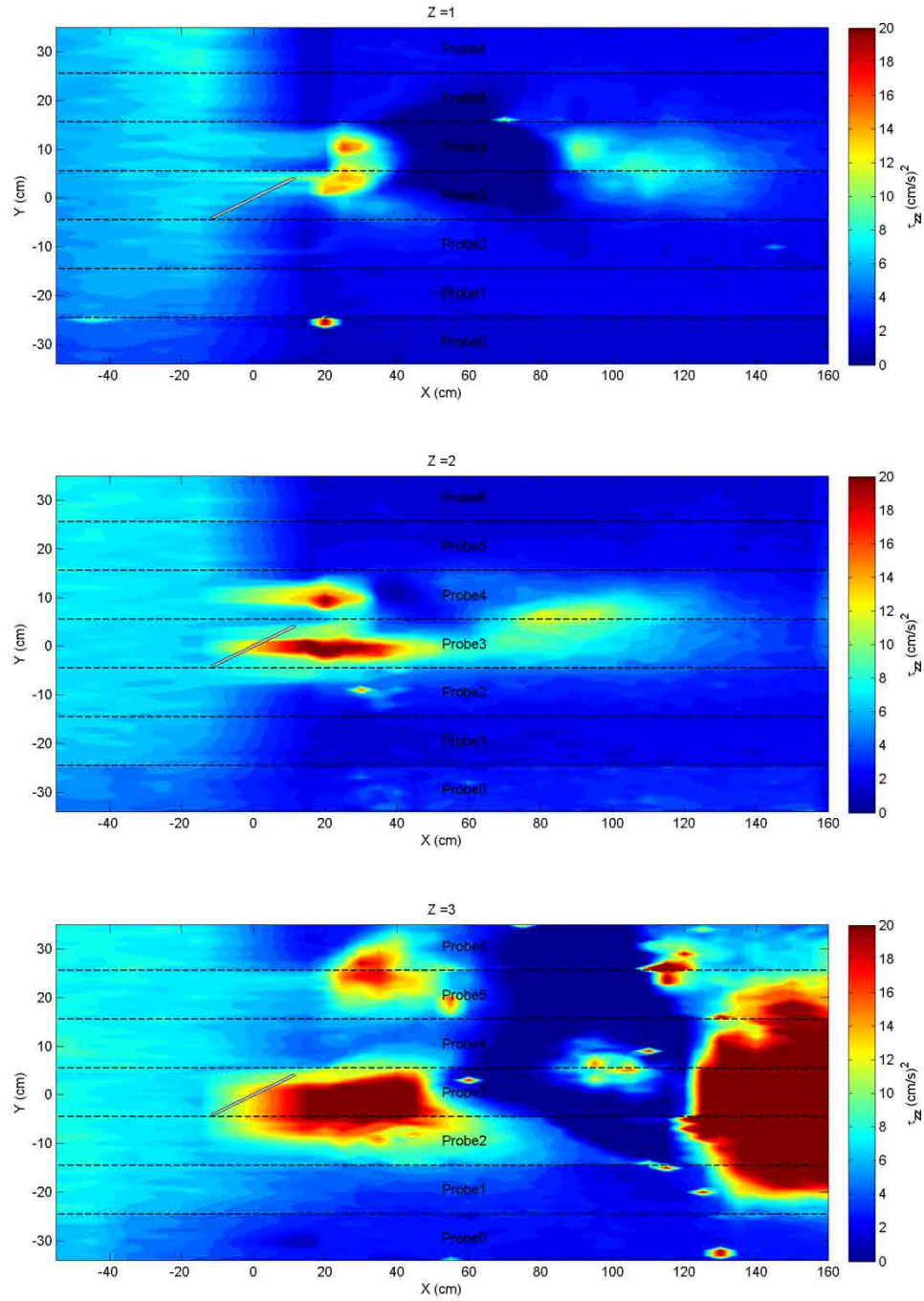




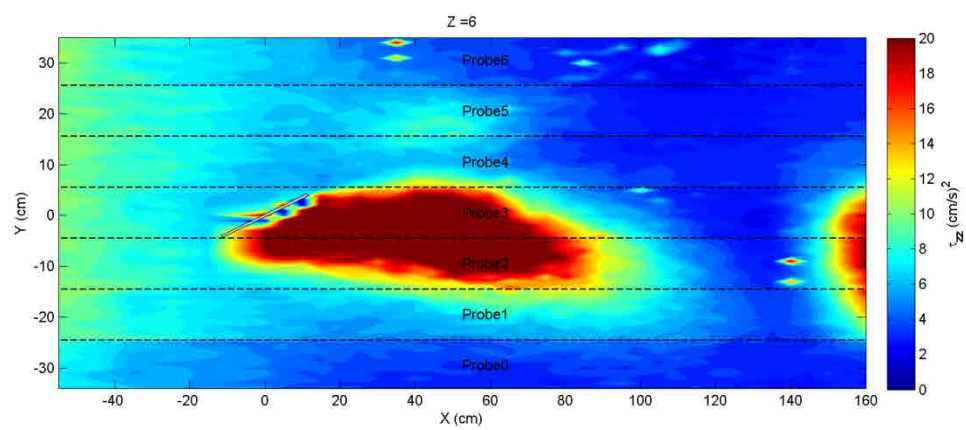
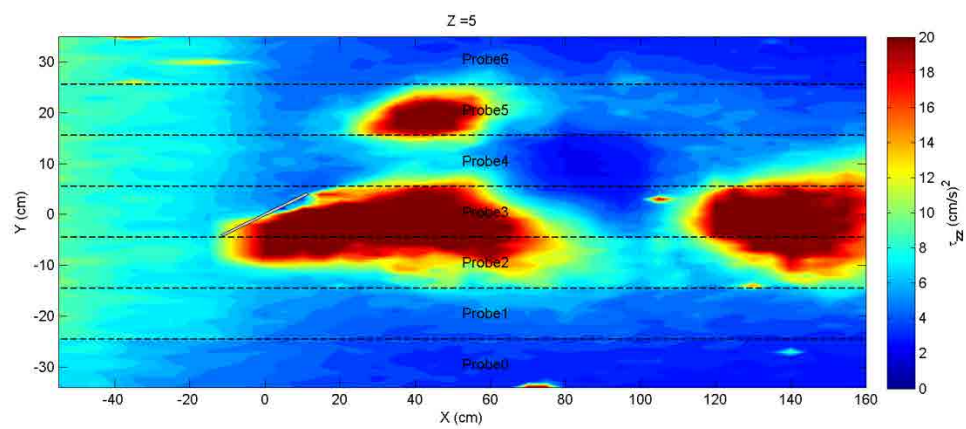
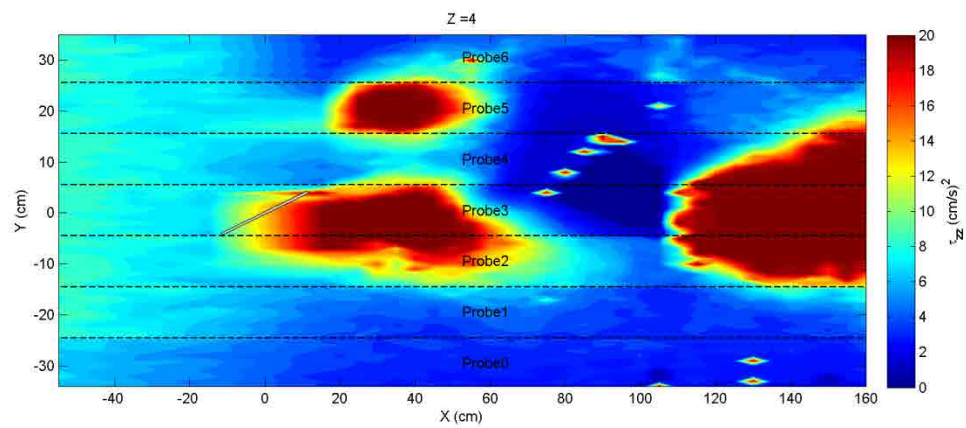


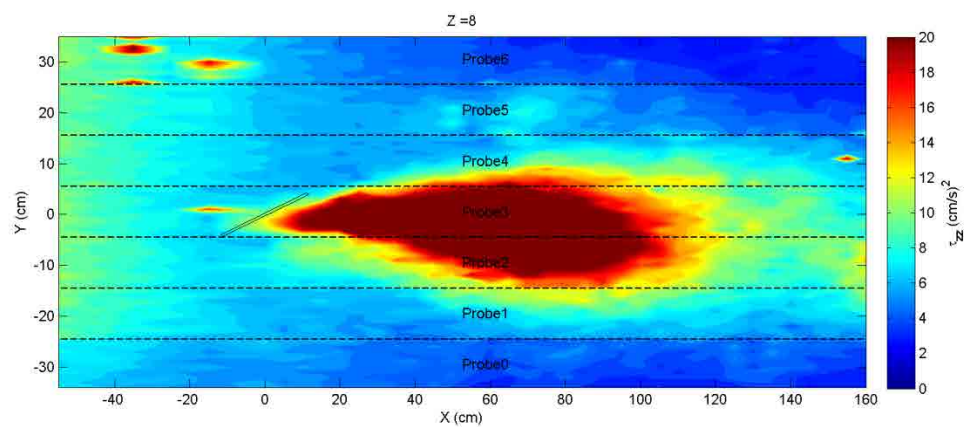
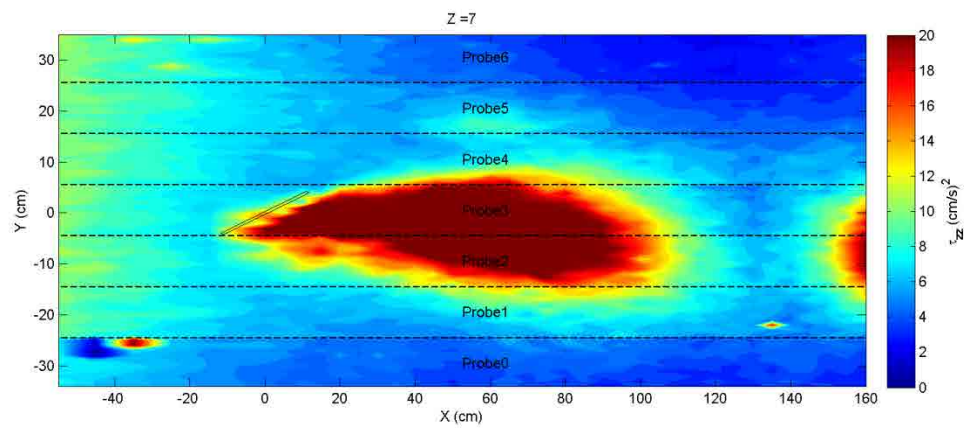


## 7. Reynolds Normal Stresses $\tau_{zz}$ in x and y-Directions

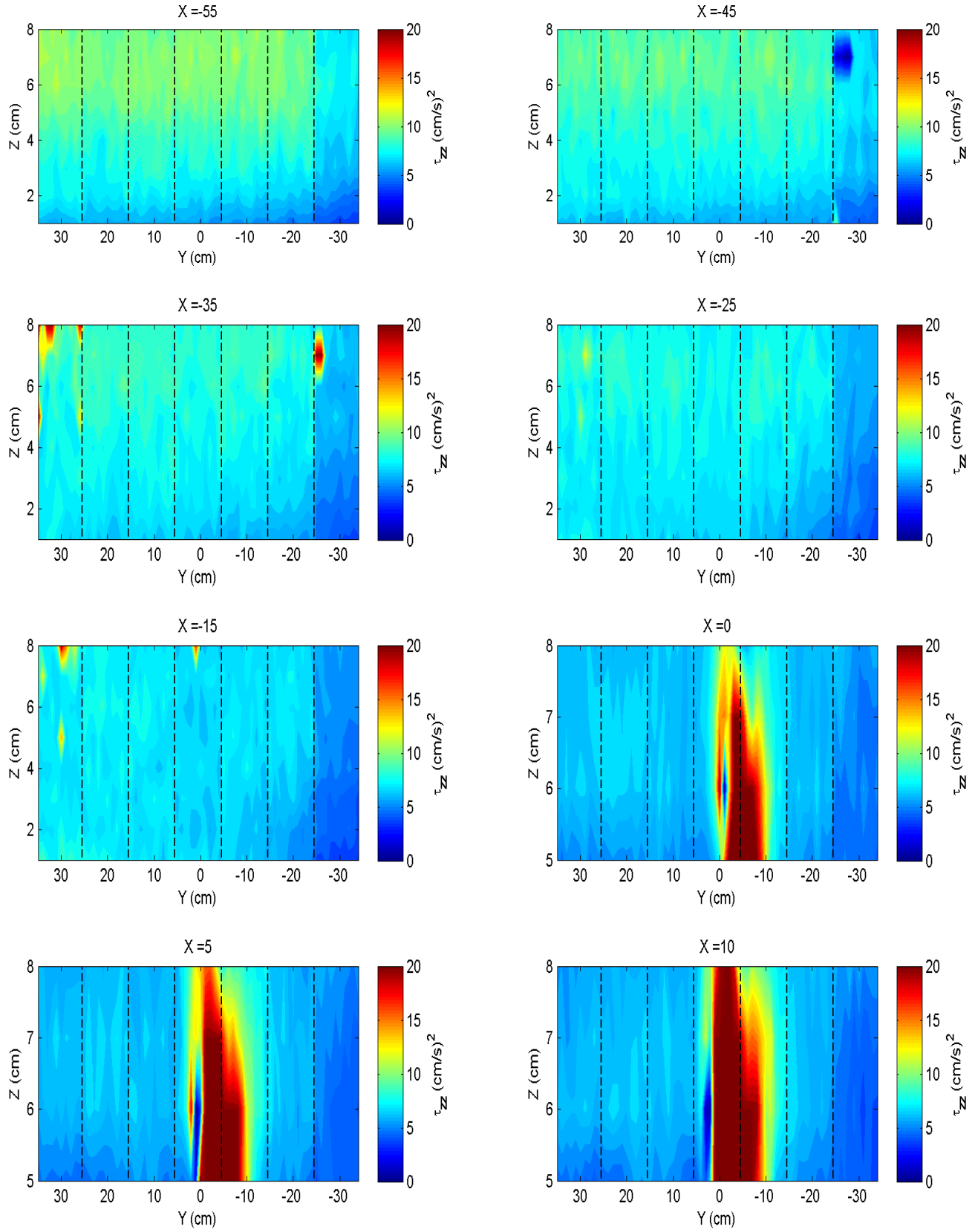


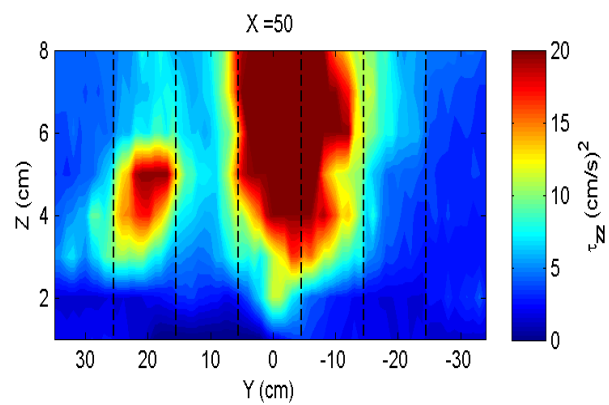
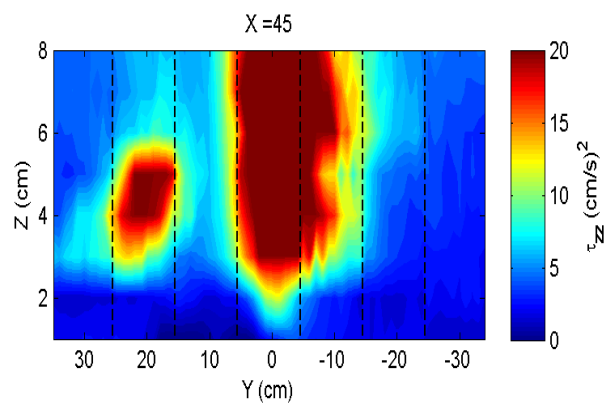
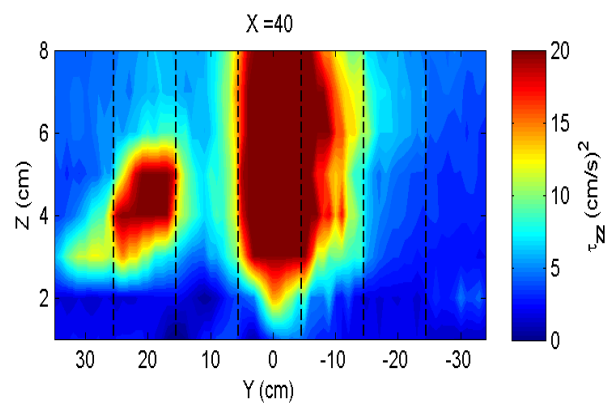
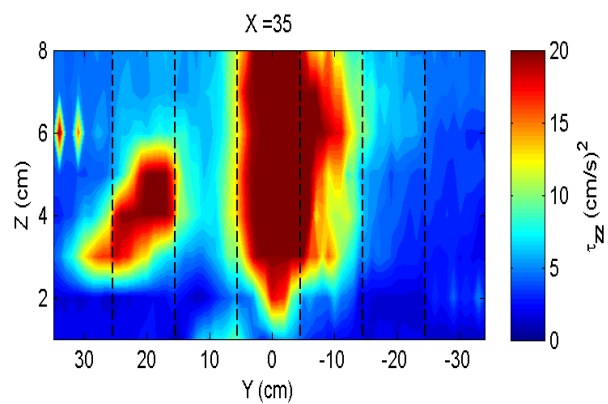
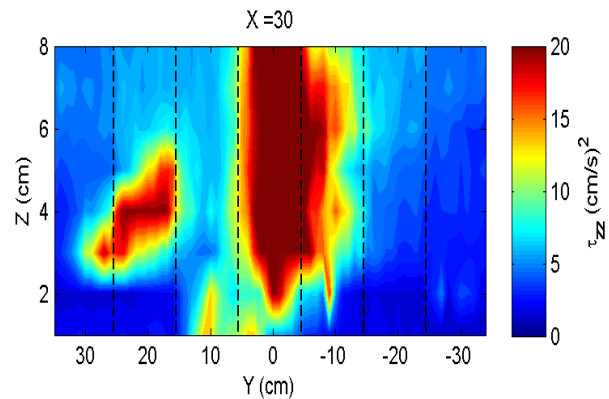
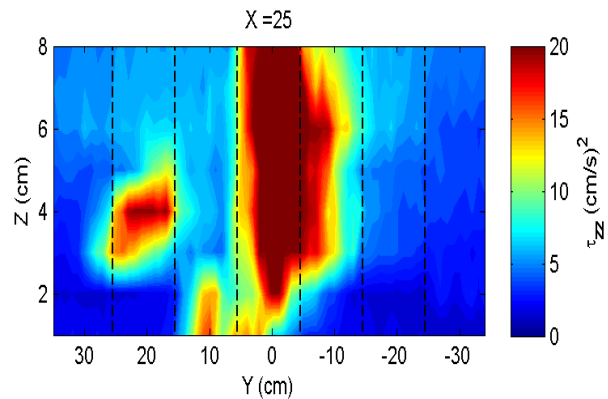
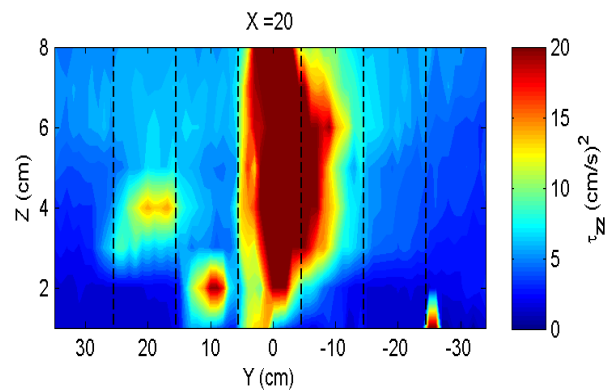
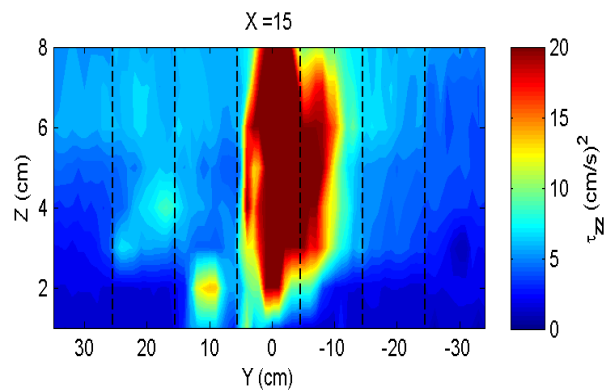


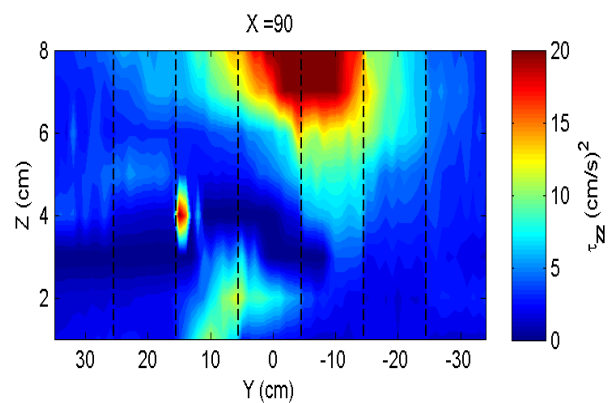
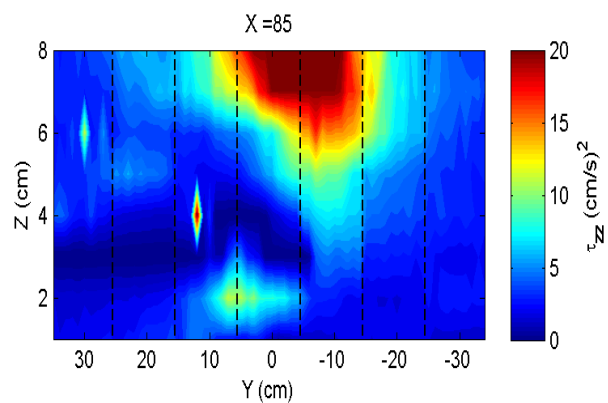
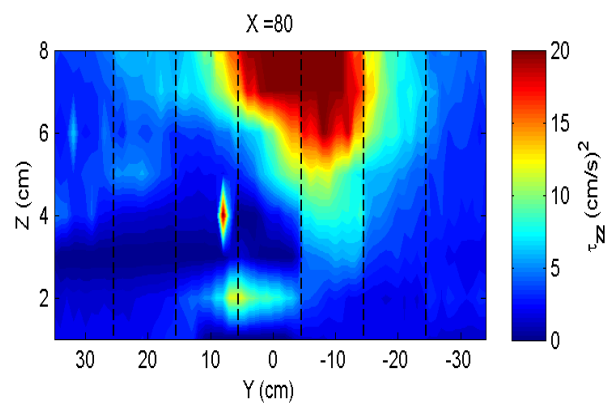
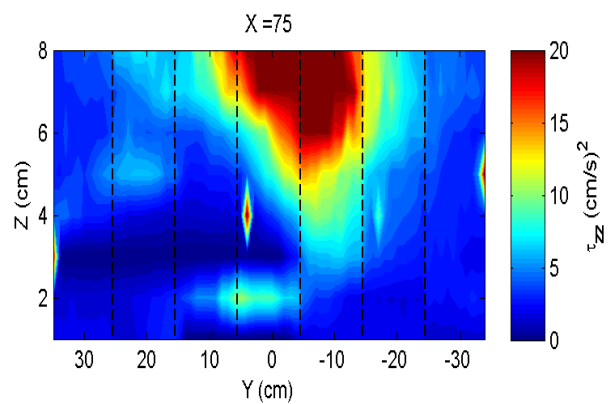
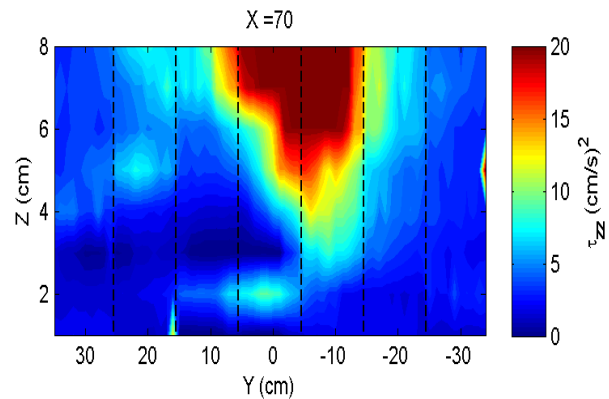
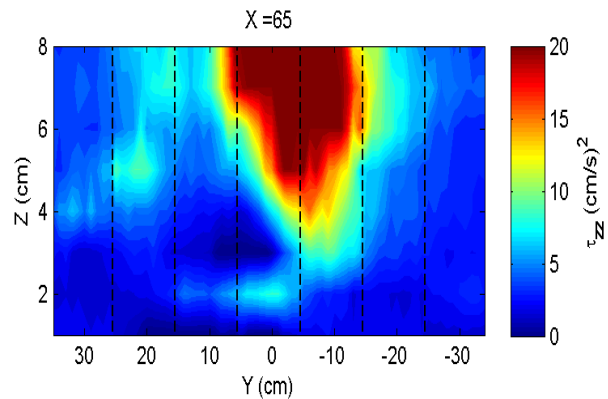
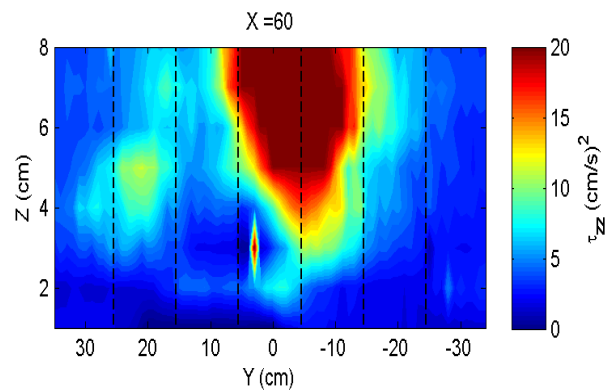
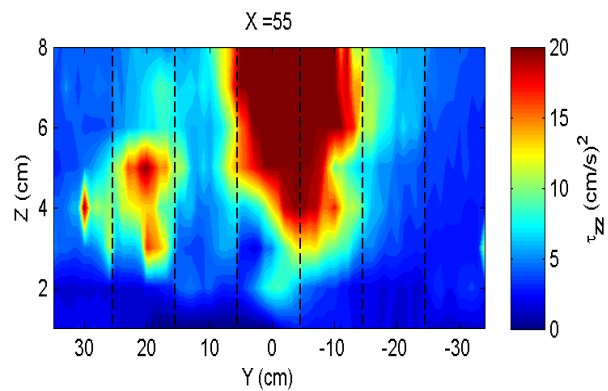


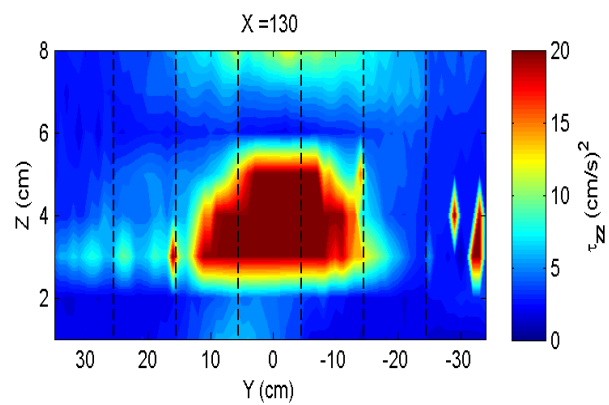
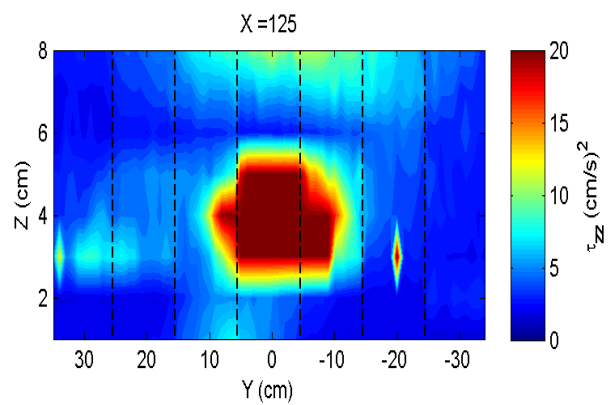
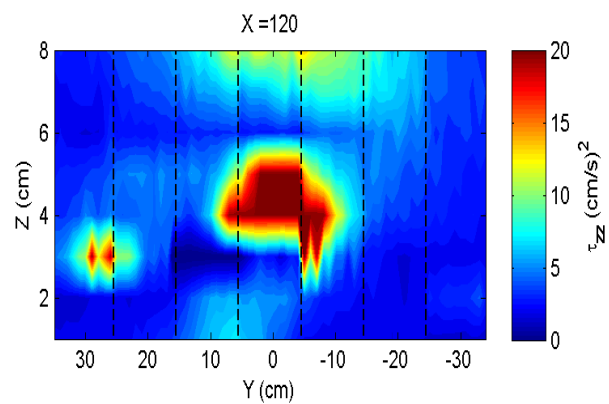
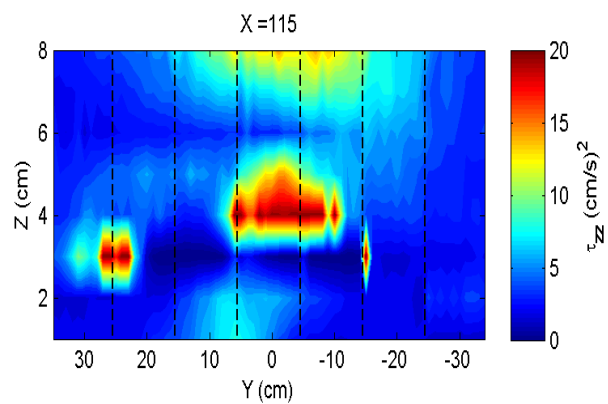
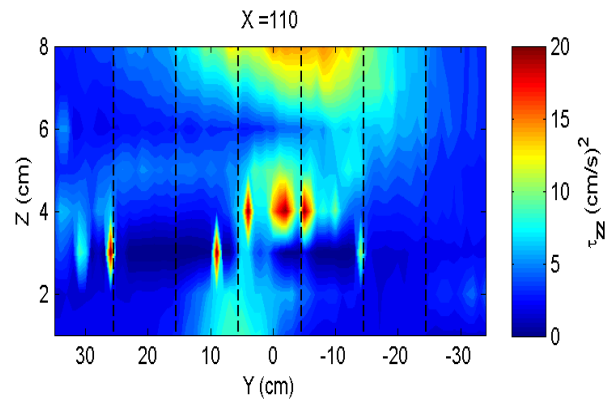
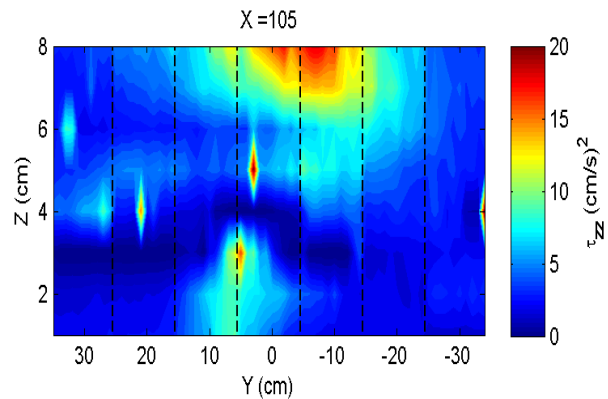
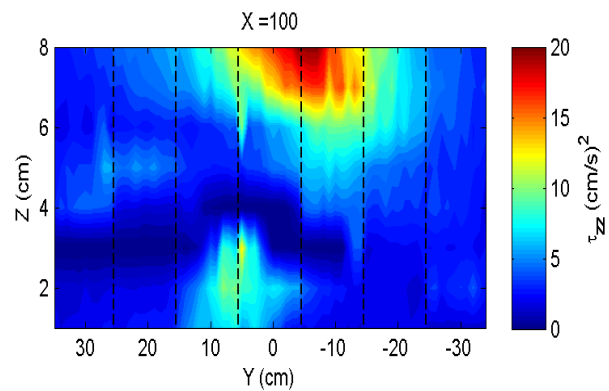
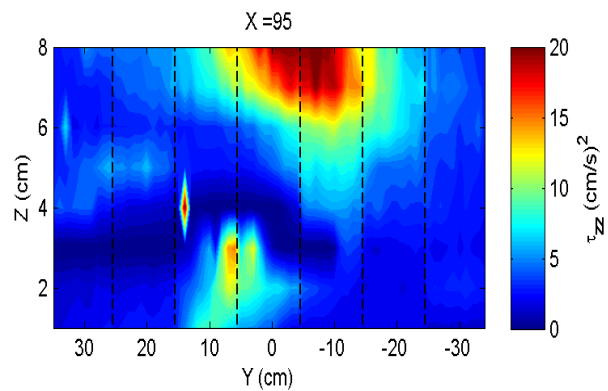


## 8. Reynolds Normal Stresses $\tau_{zz}$ in y and z-Directions

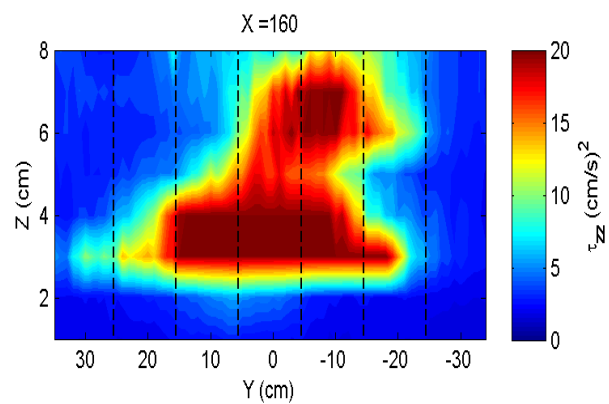
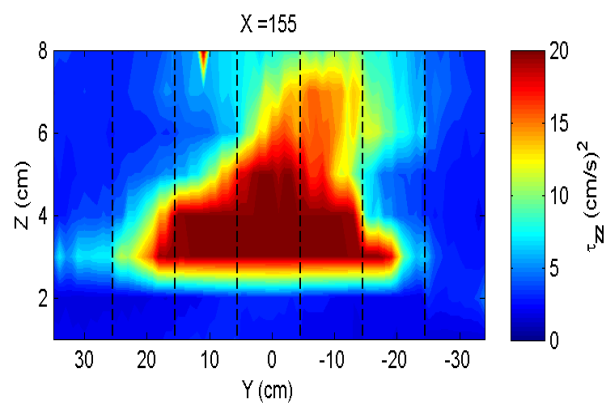
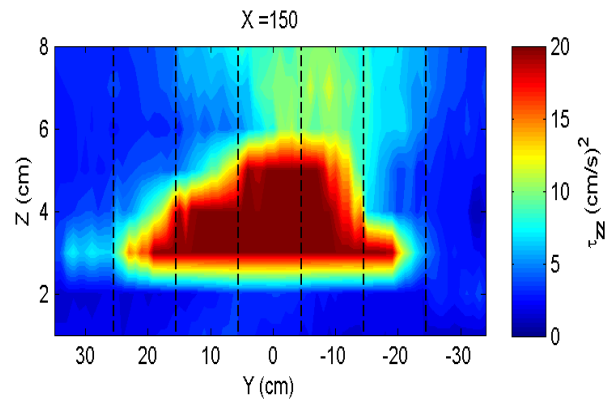
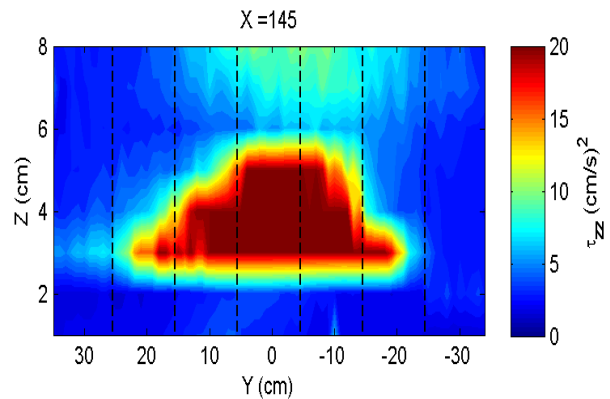
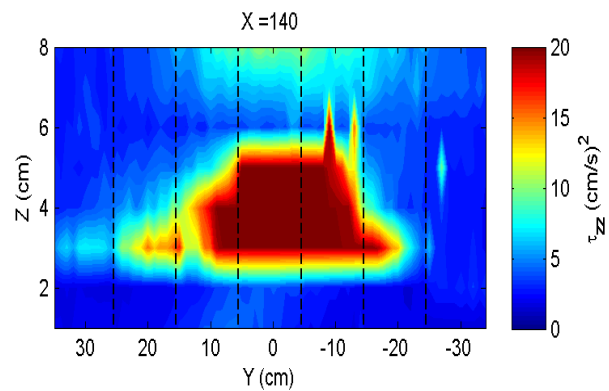
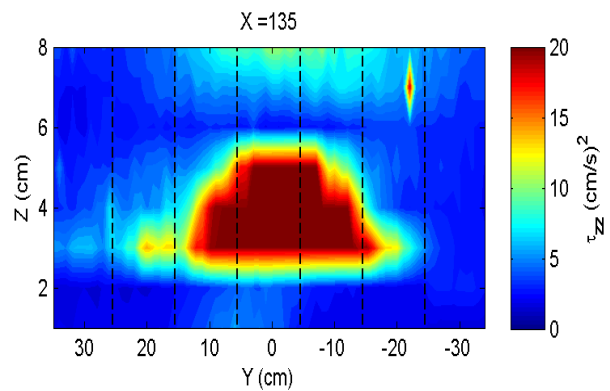




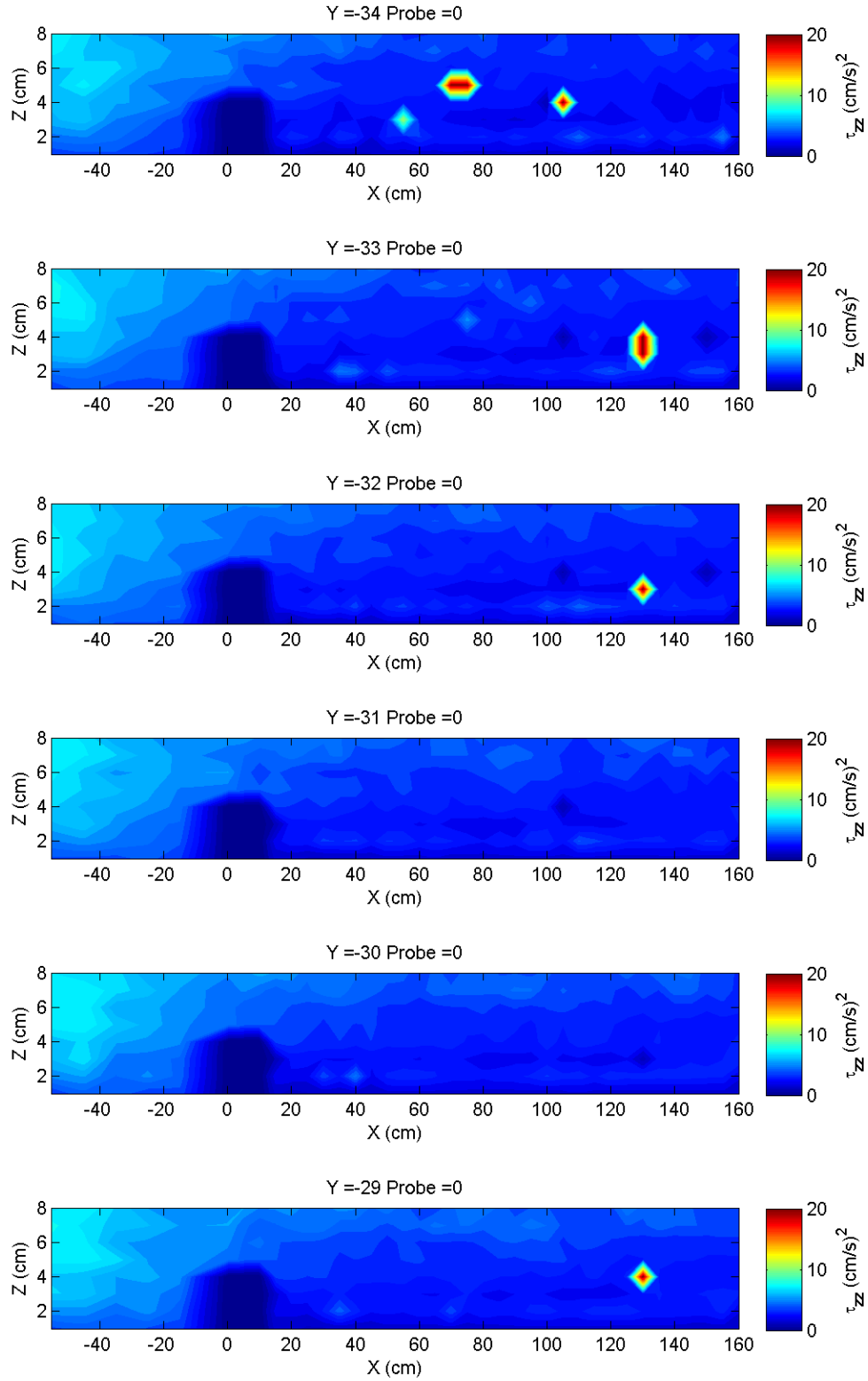




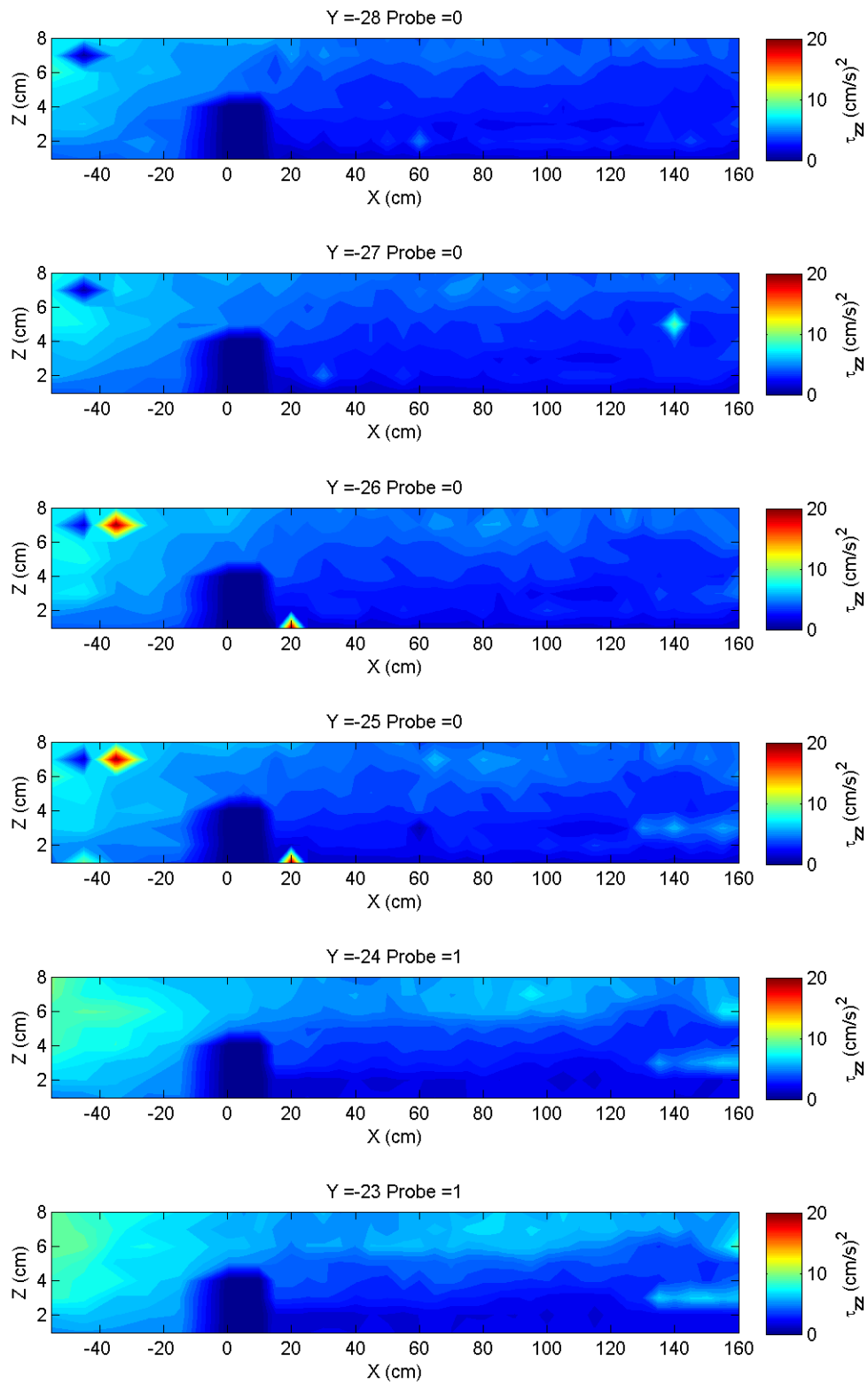


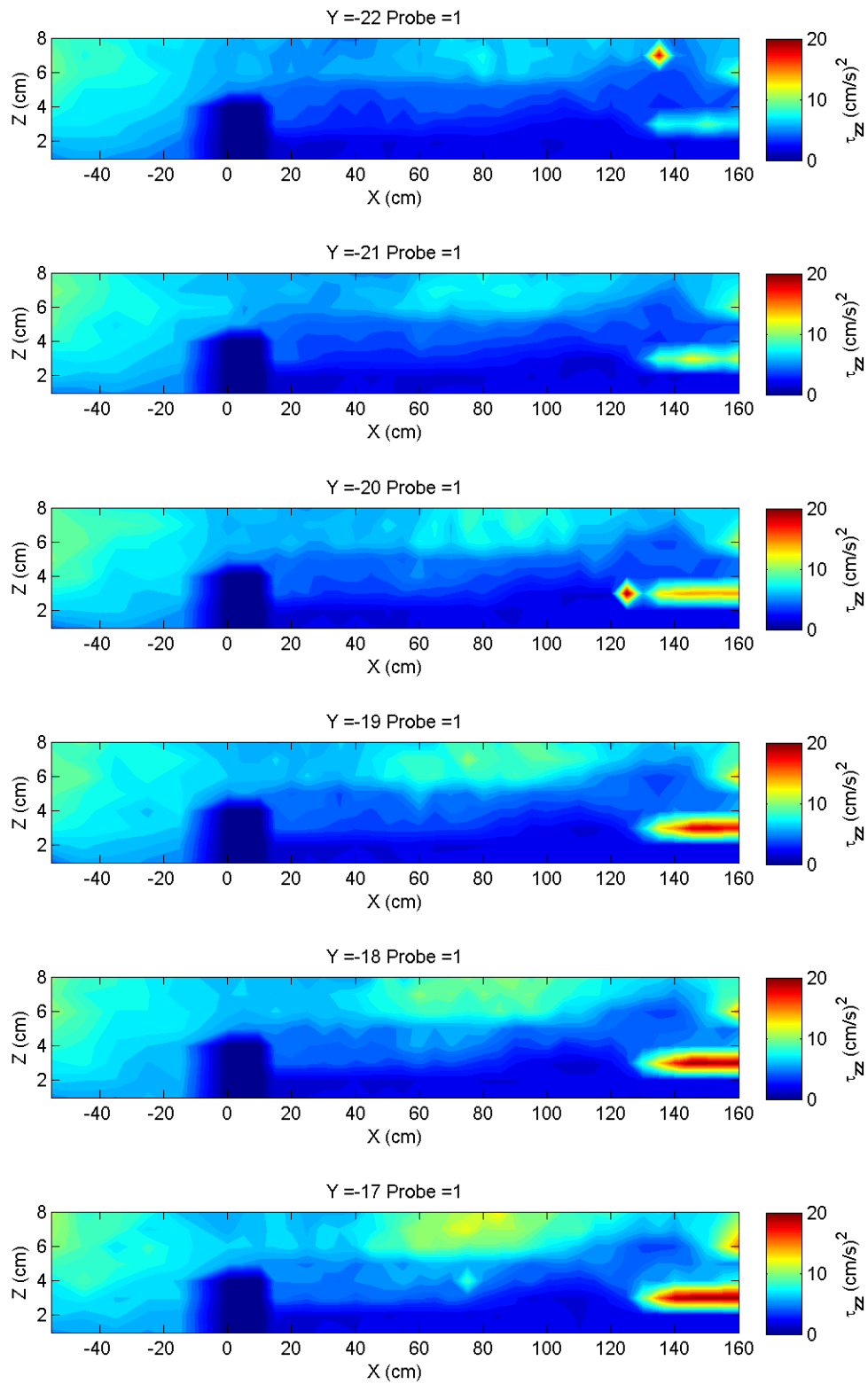


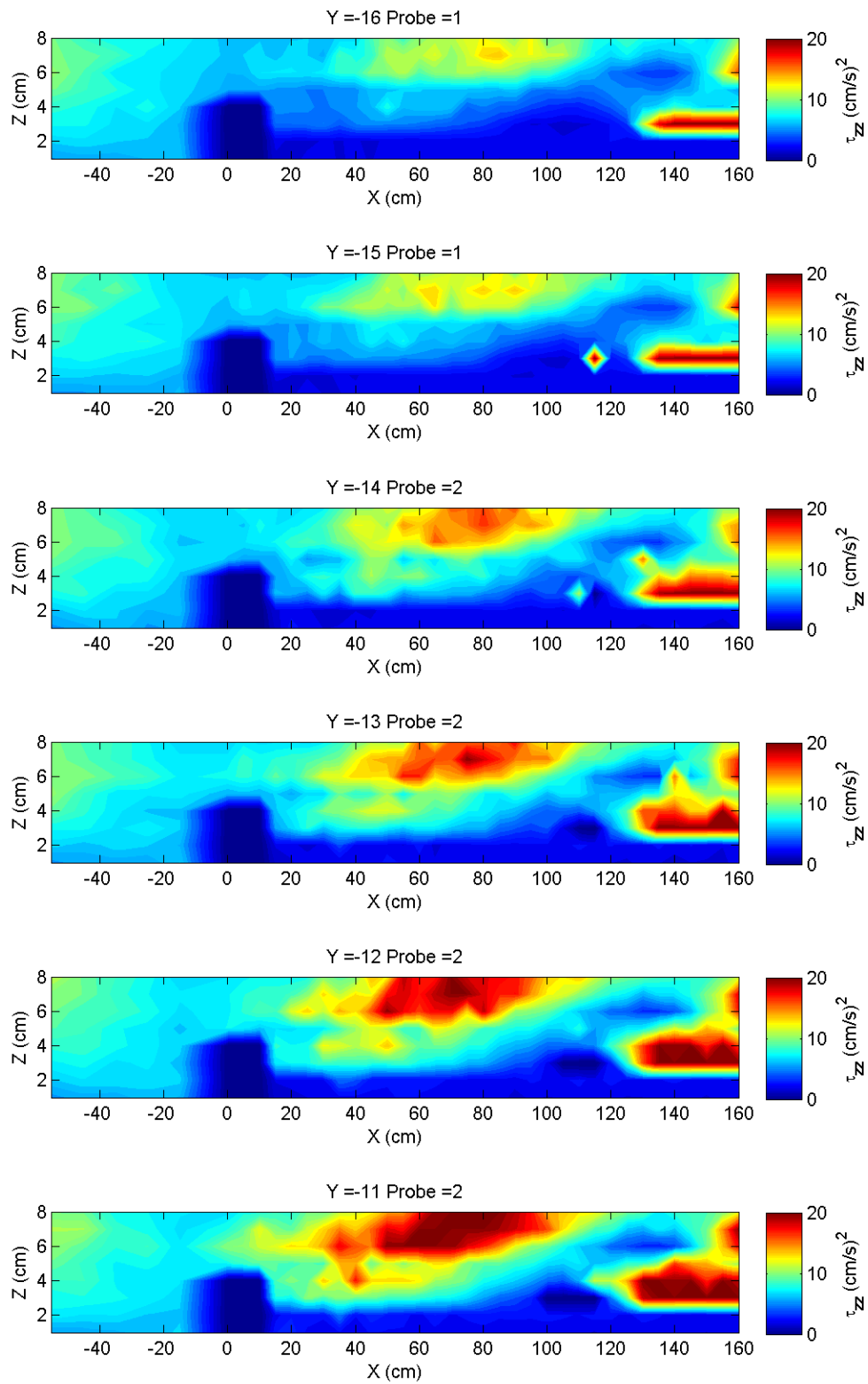
## 9. Reynolds Normal Stresses $\tau_{zz}$ in x and z-Directions

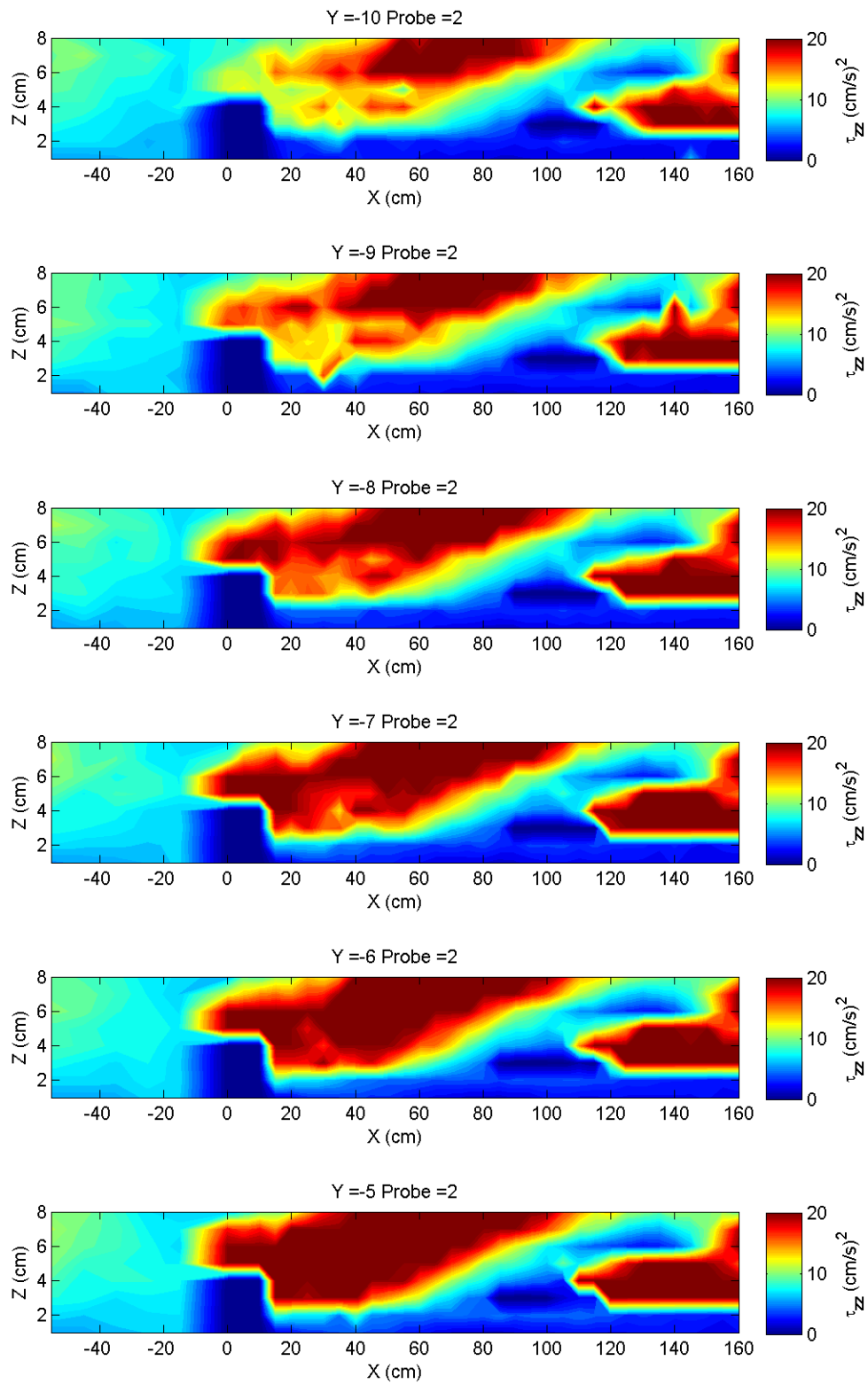


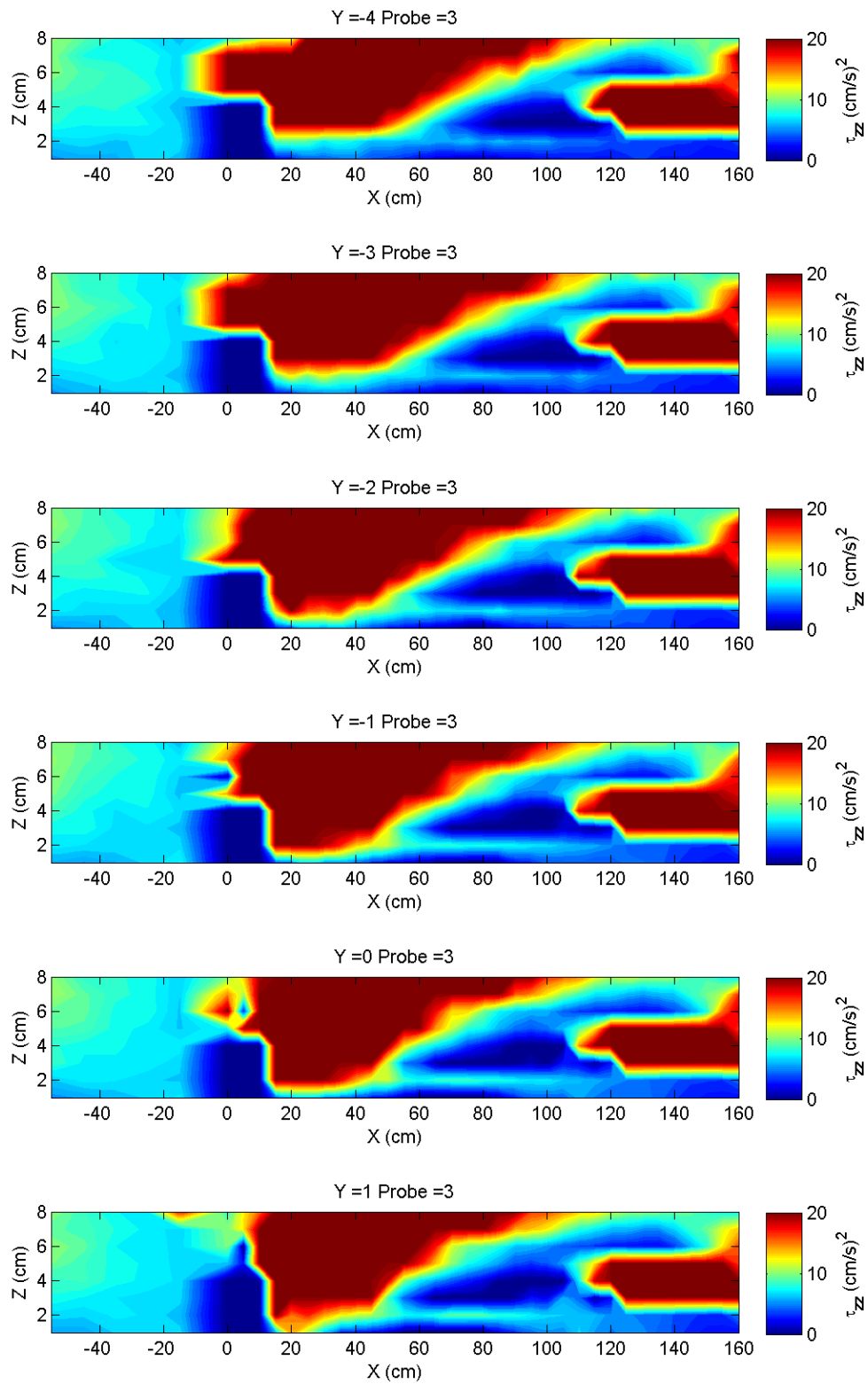


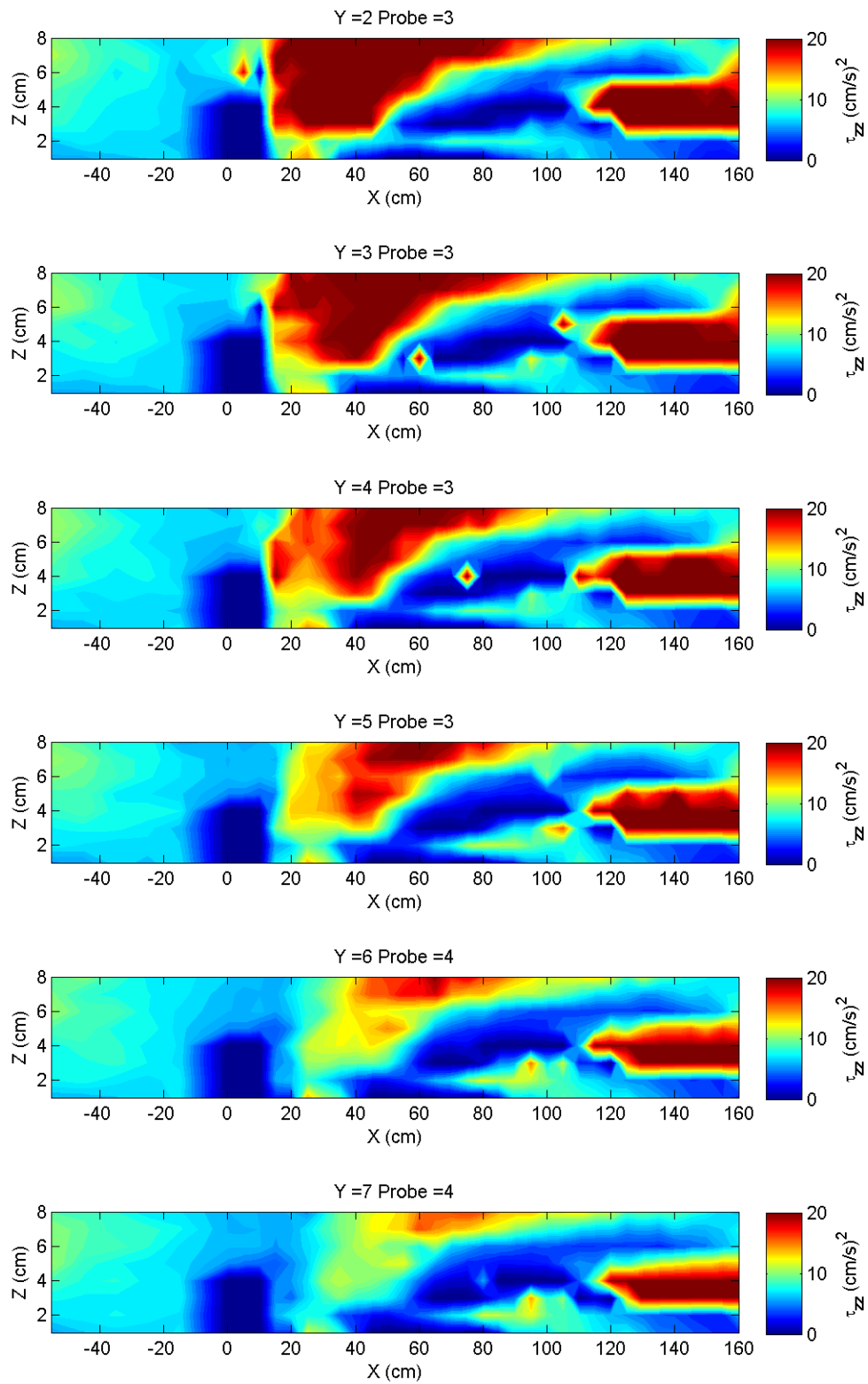


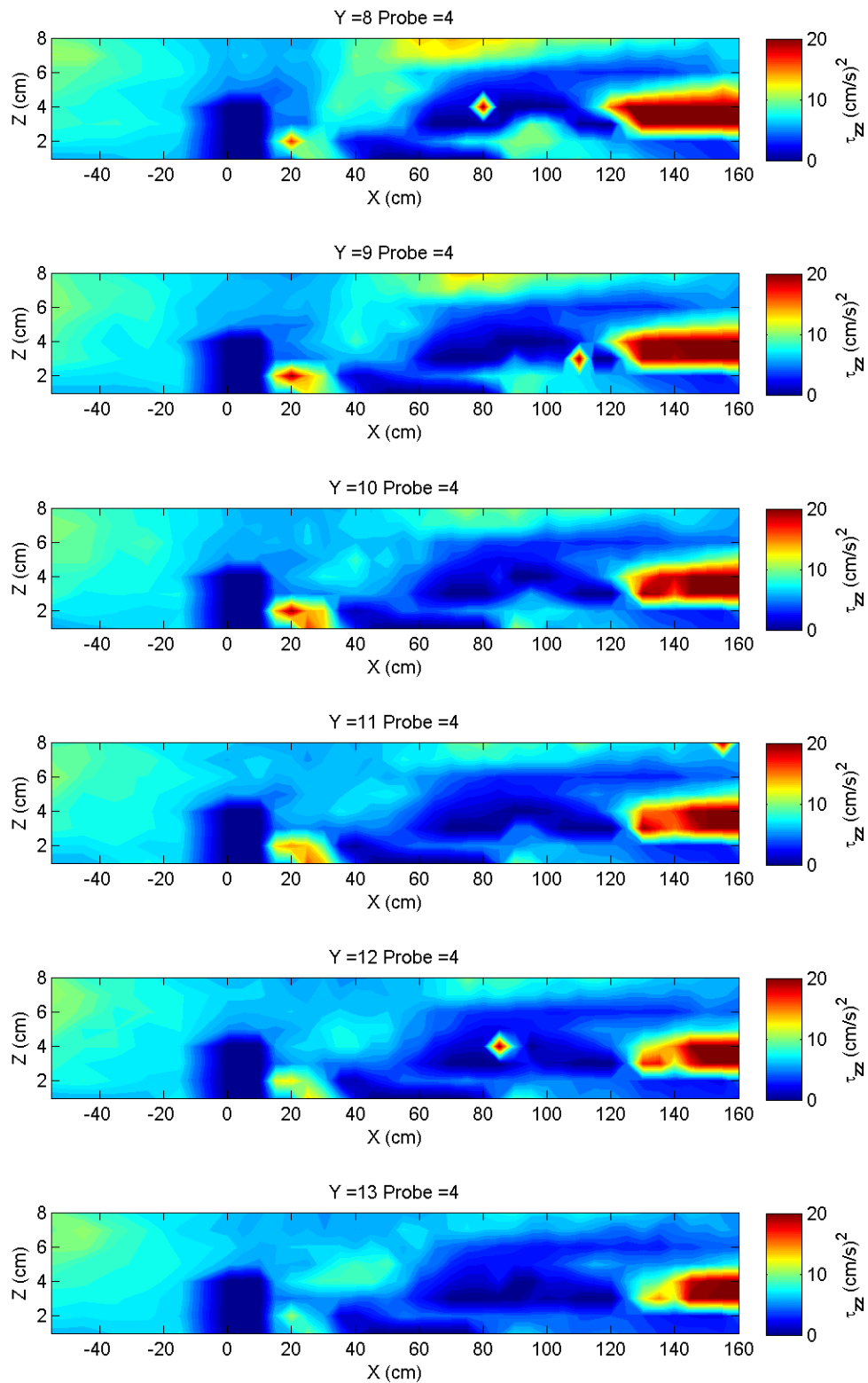


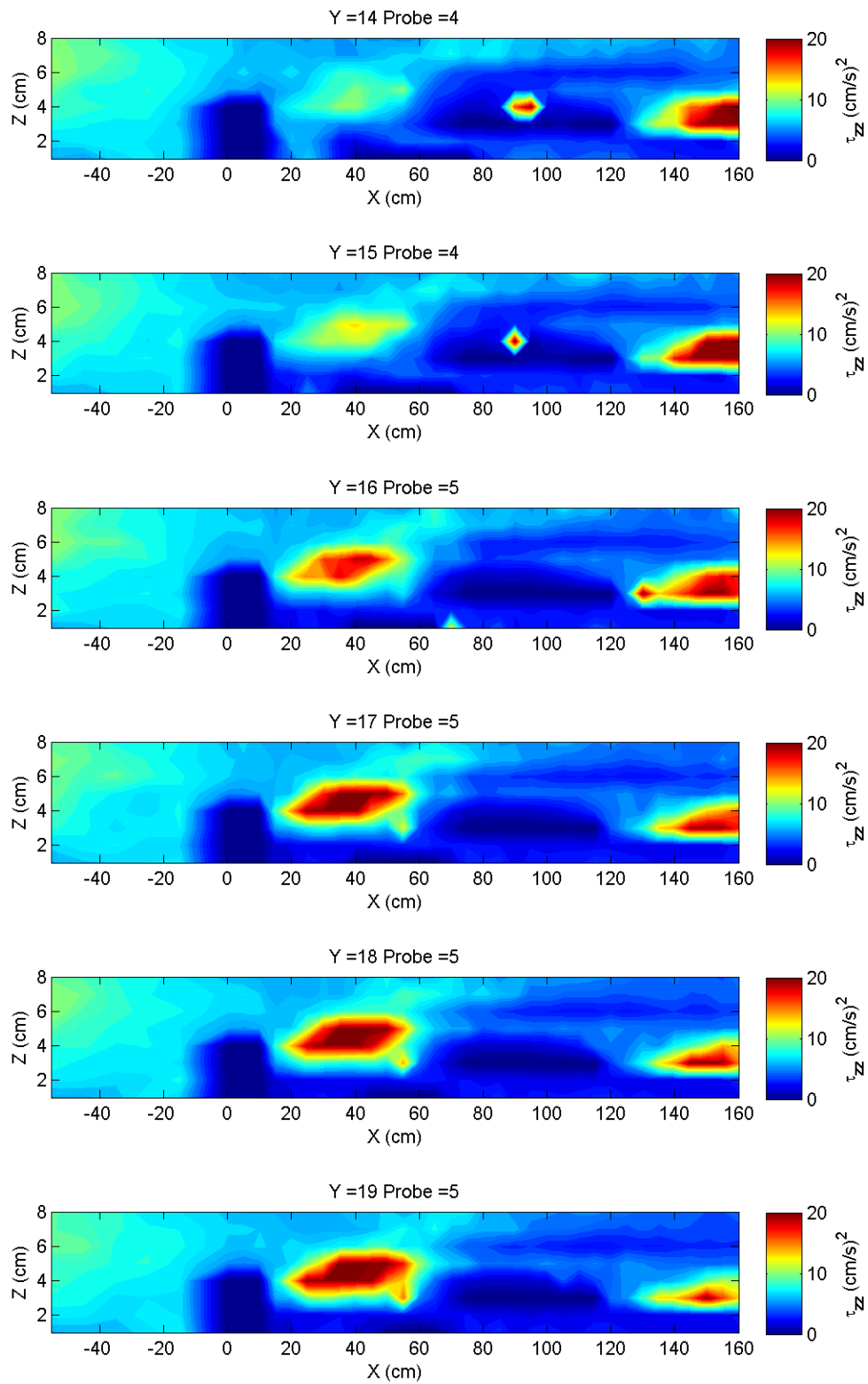




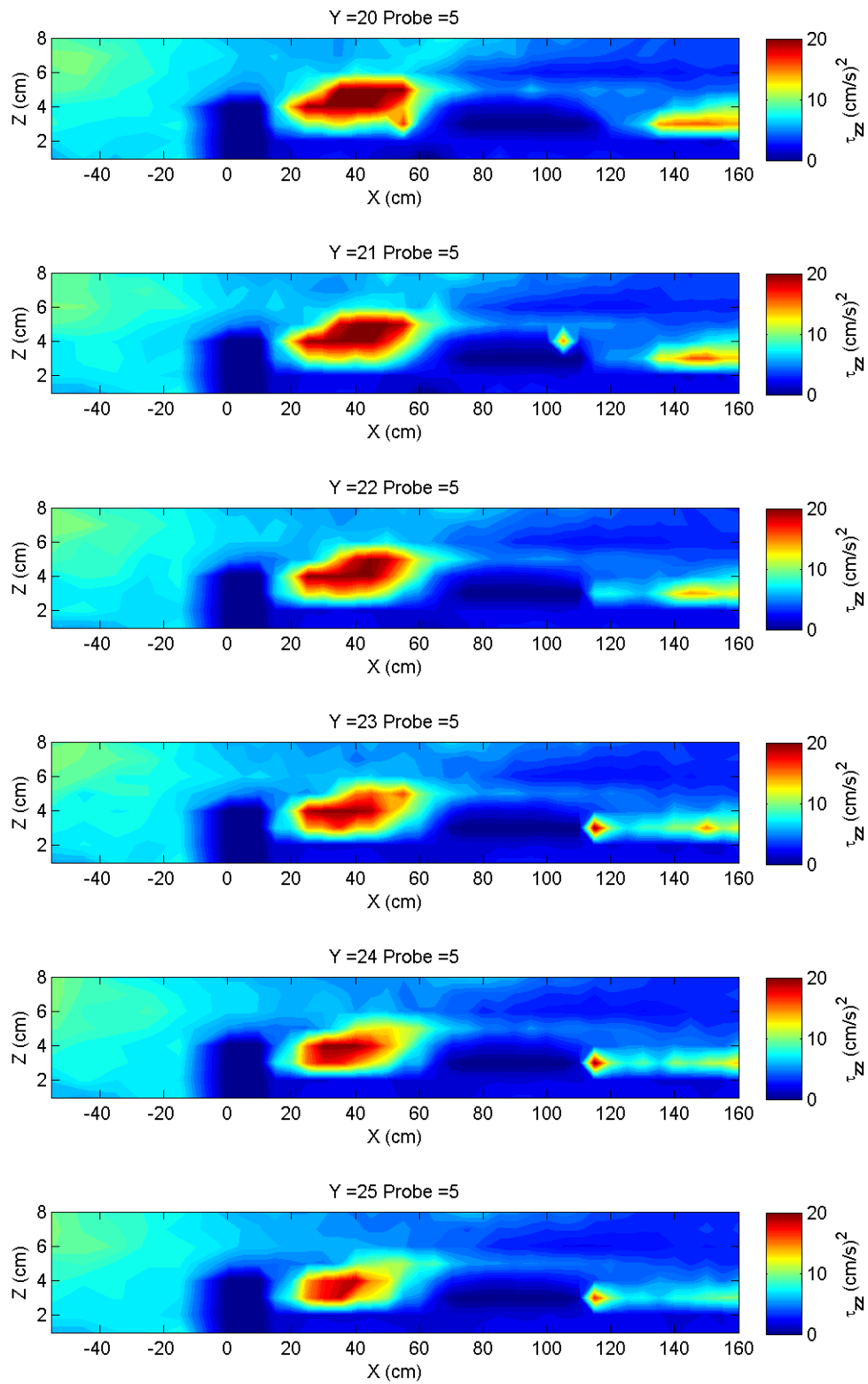


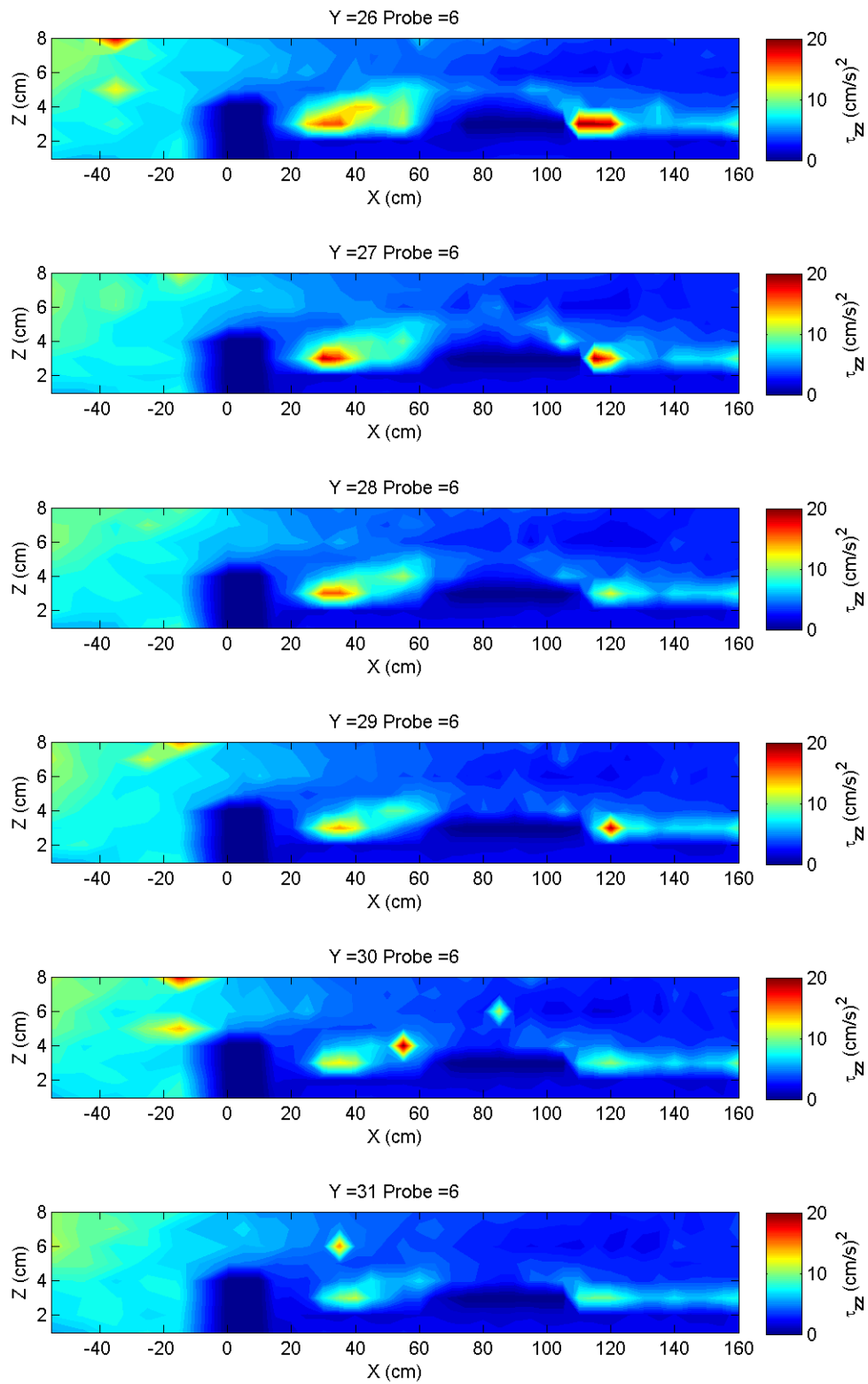


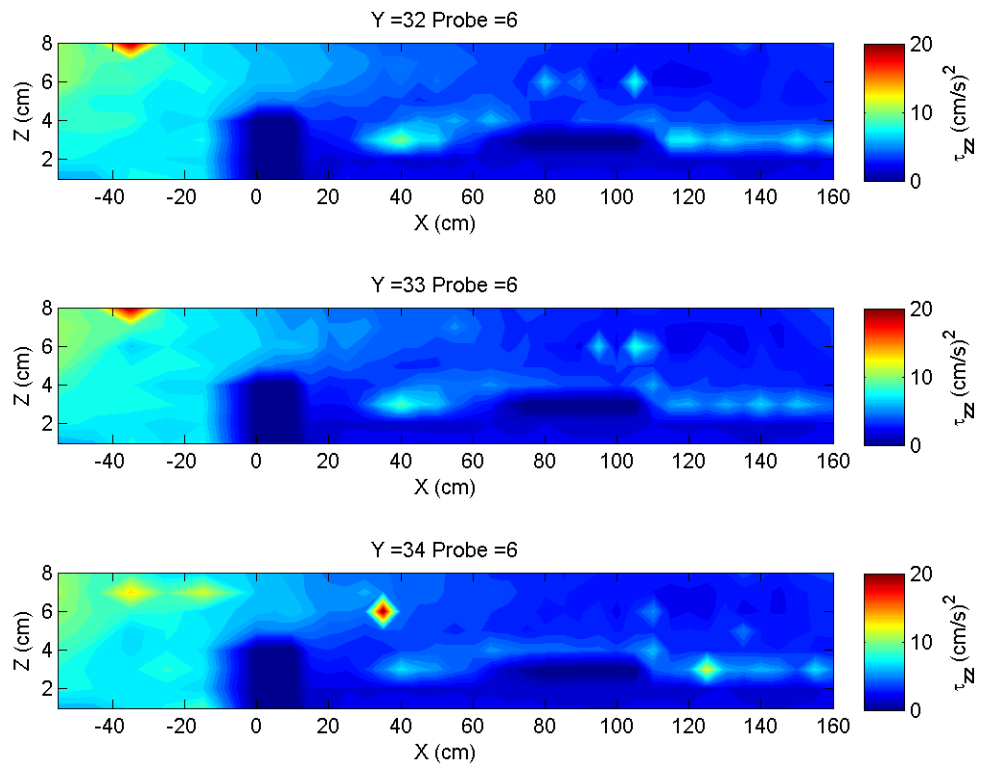




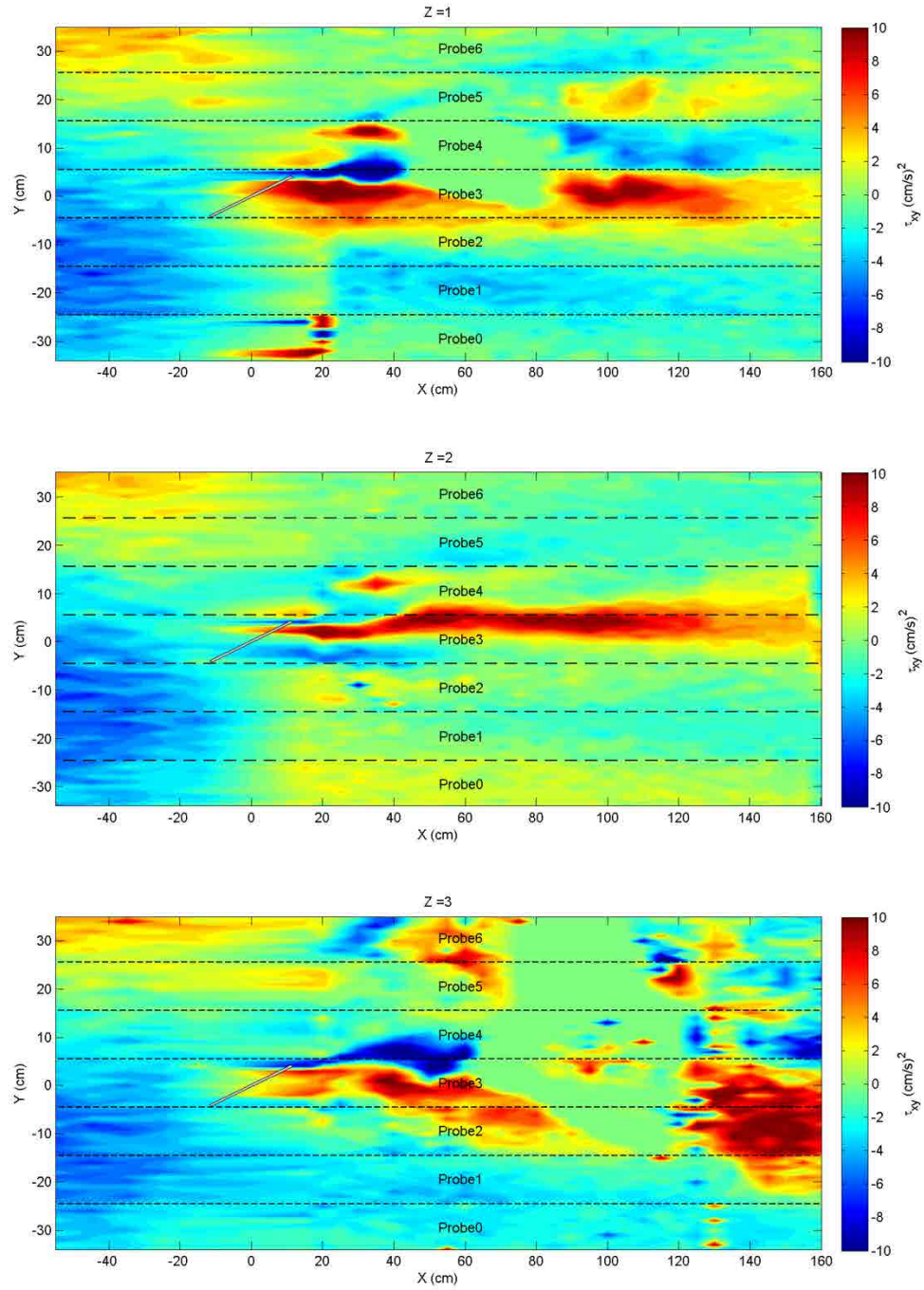


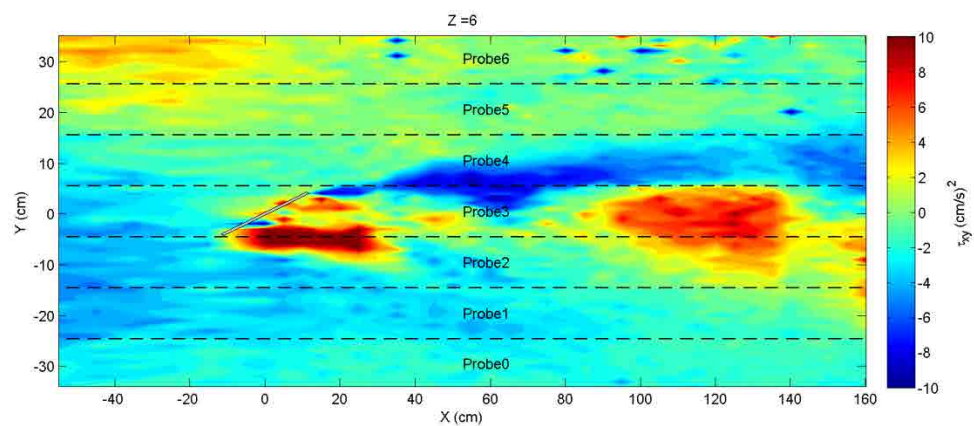
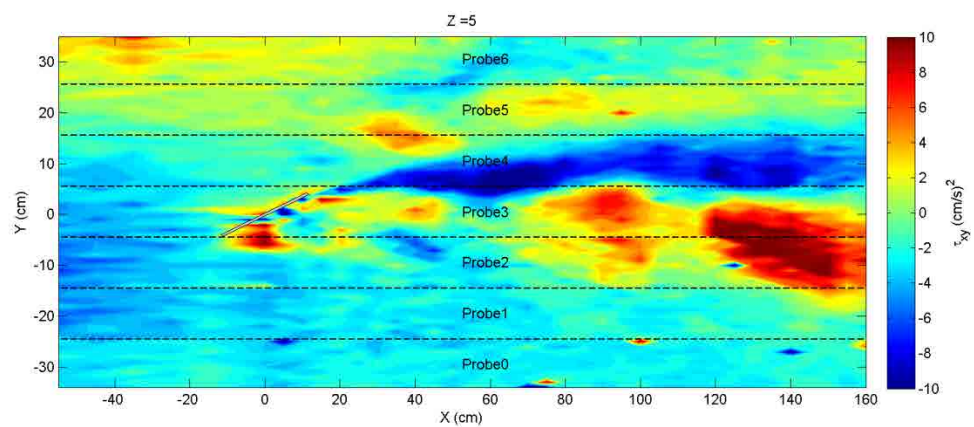
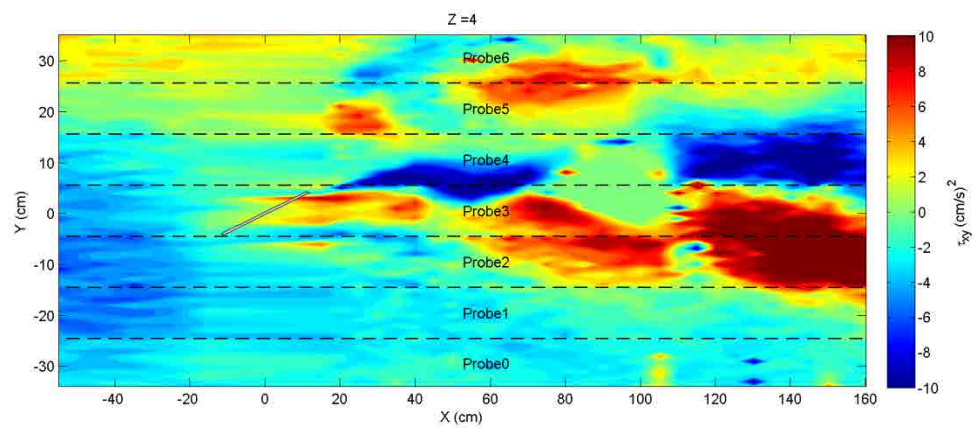




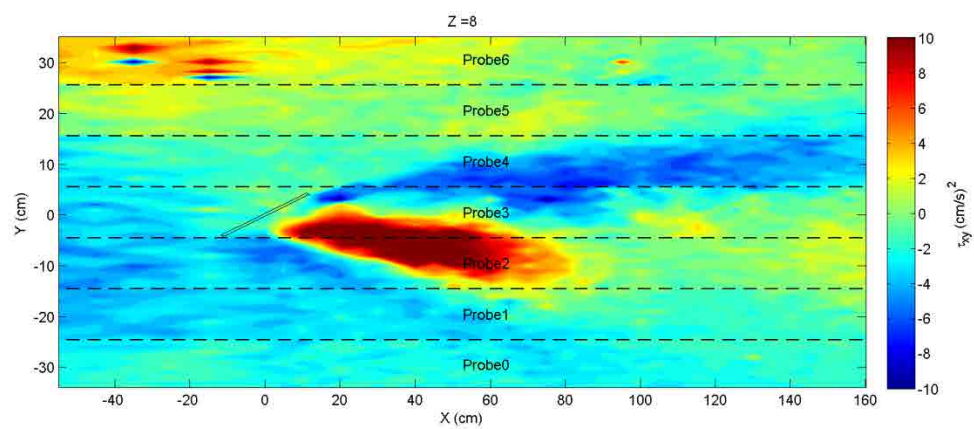
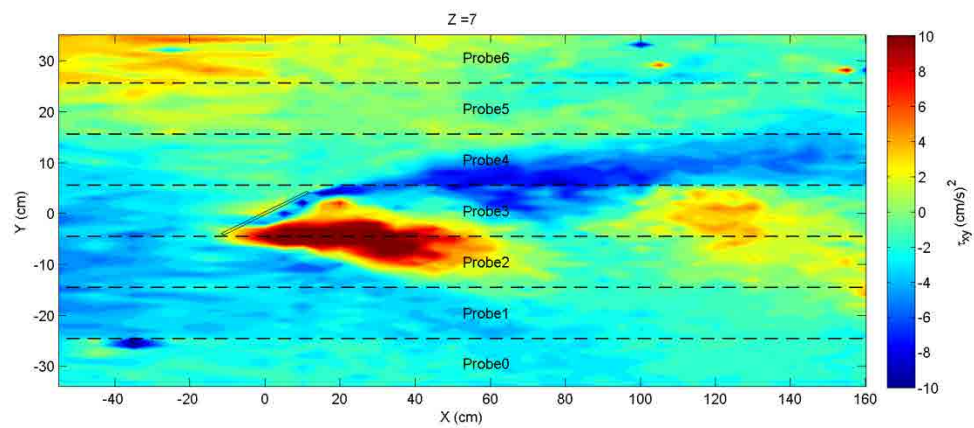


## 10. Reynolds Shear Stresses $\tau_{xy}$ in x and y-Directions

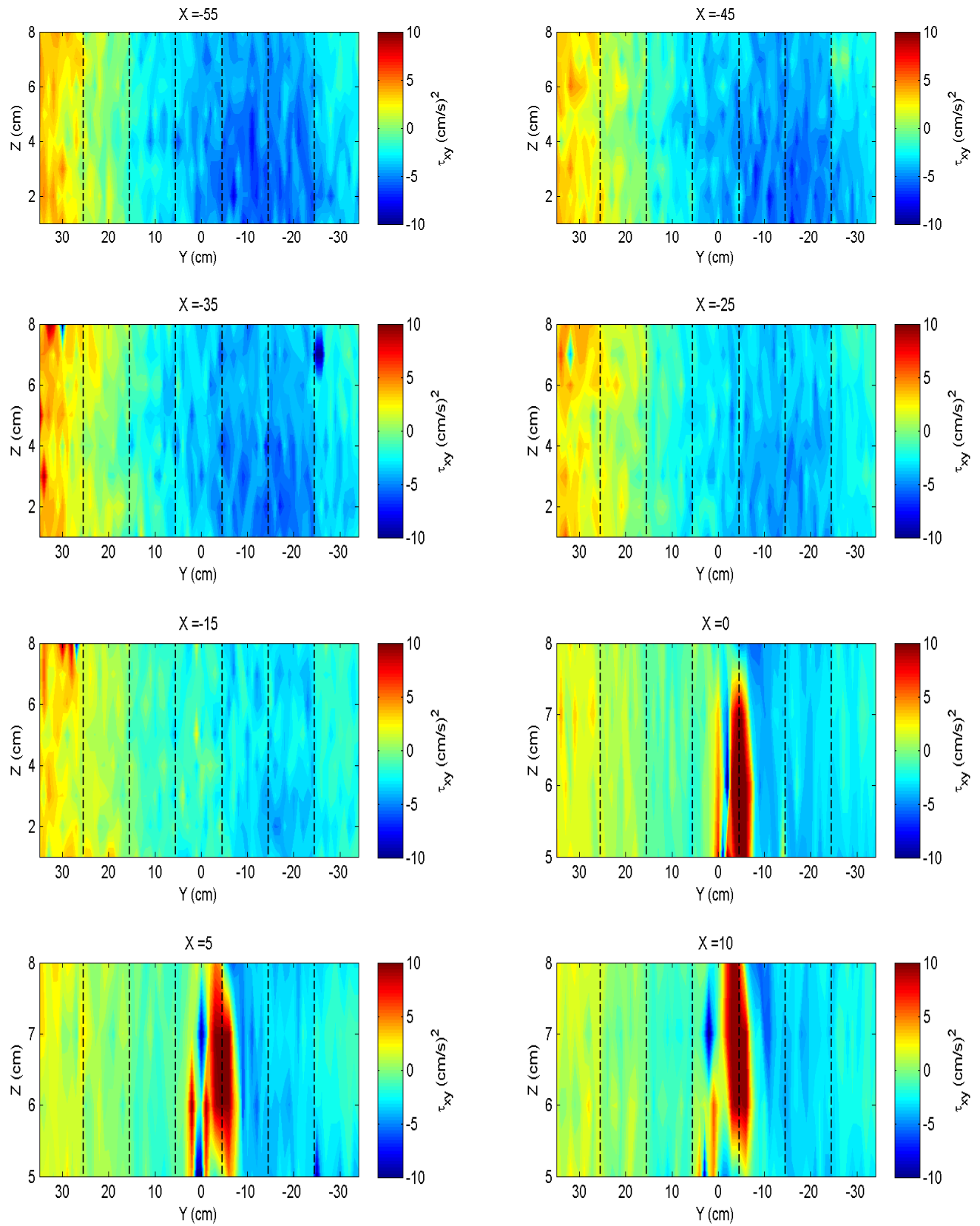


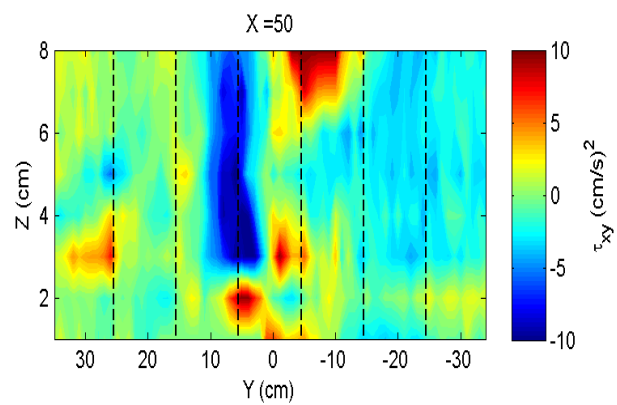
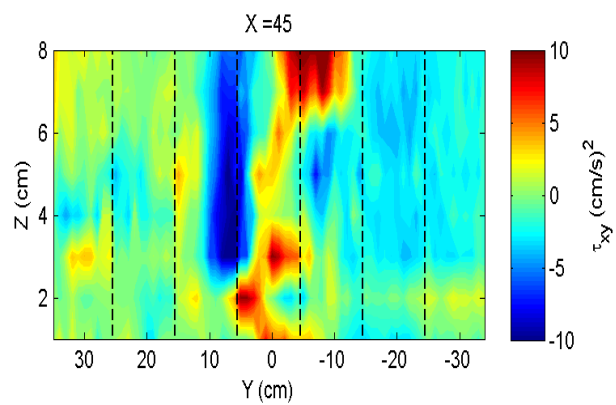
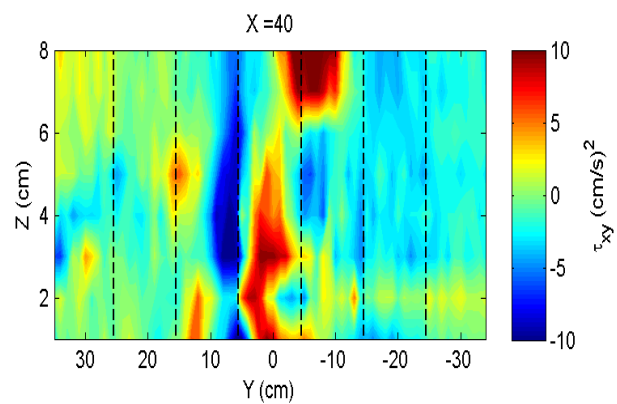
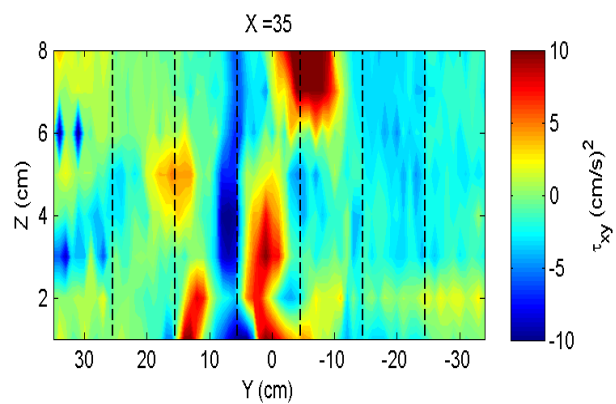
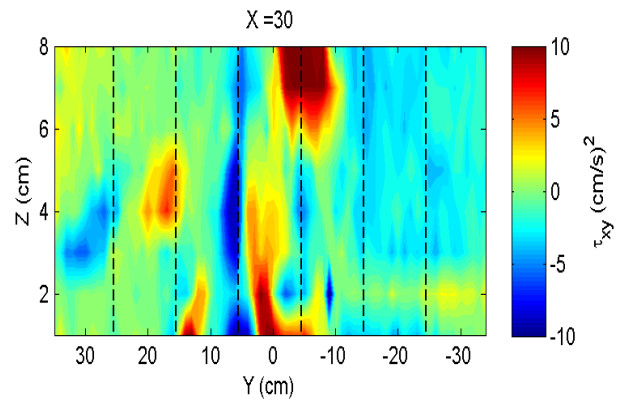
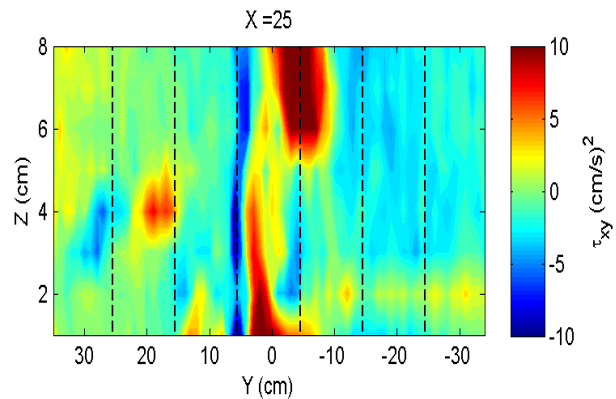
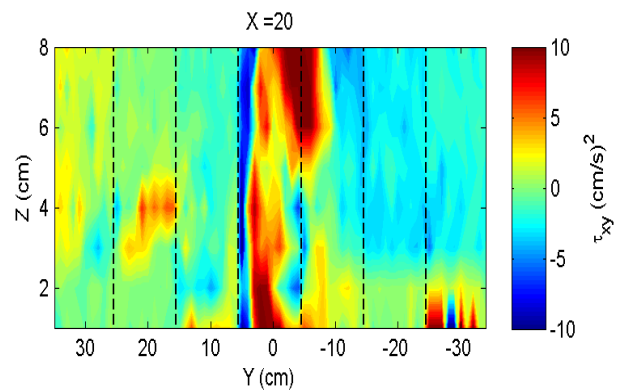
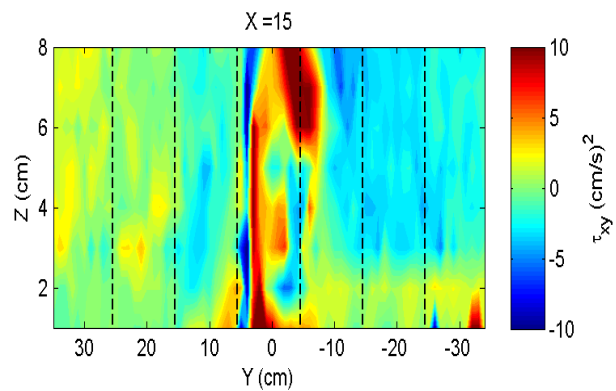




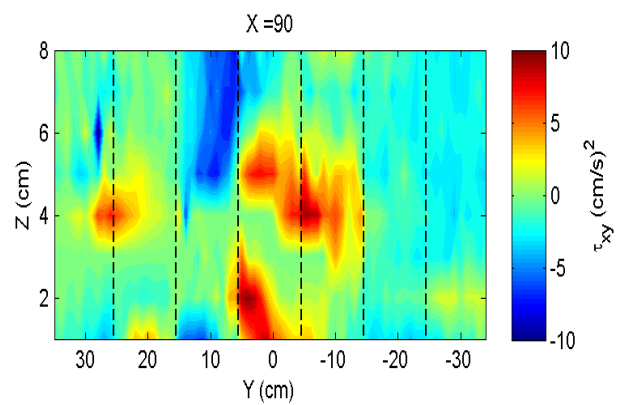
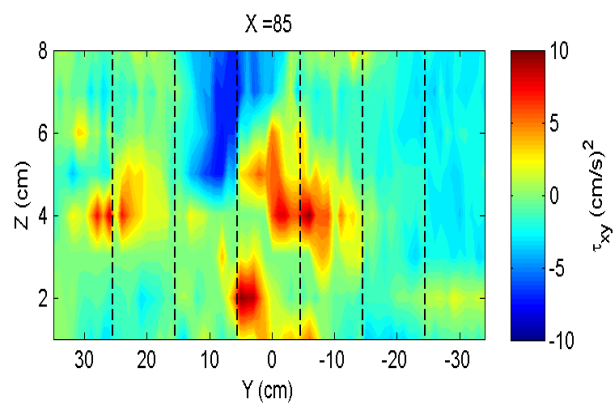
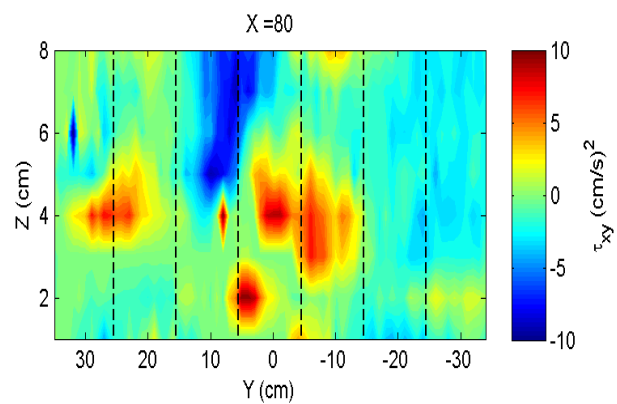
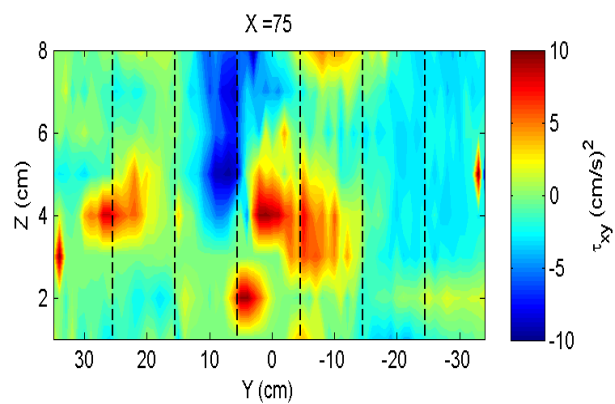
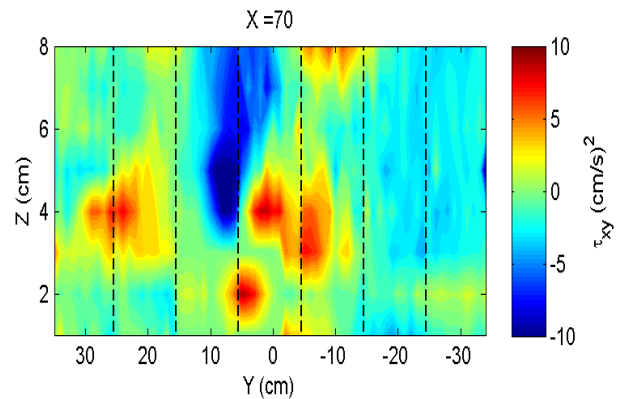
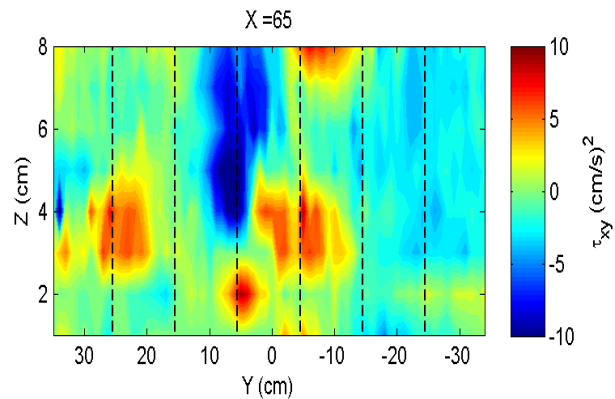
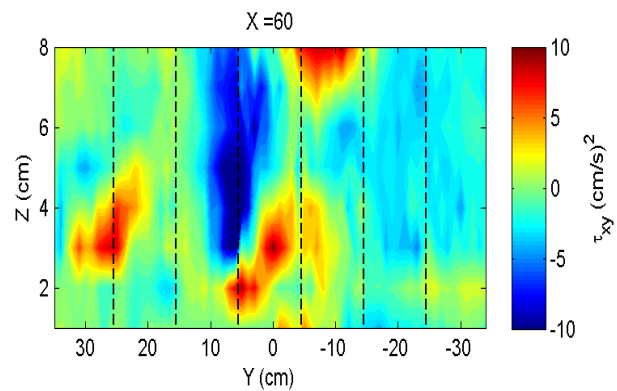
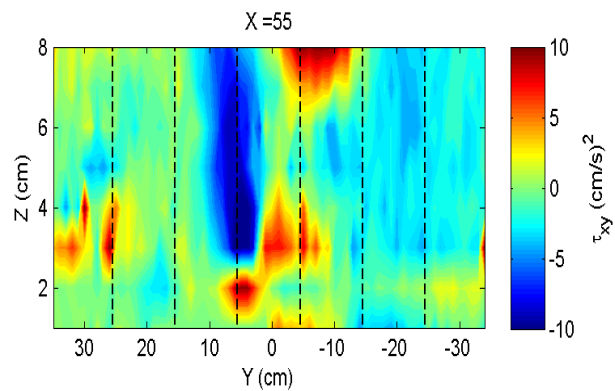


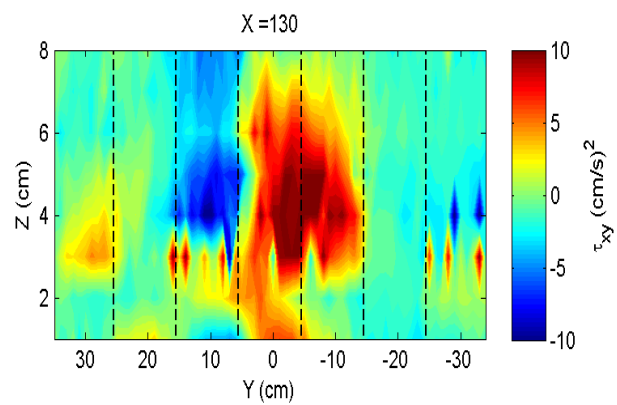
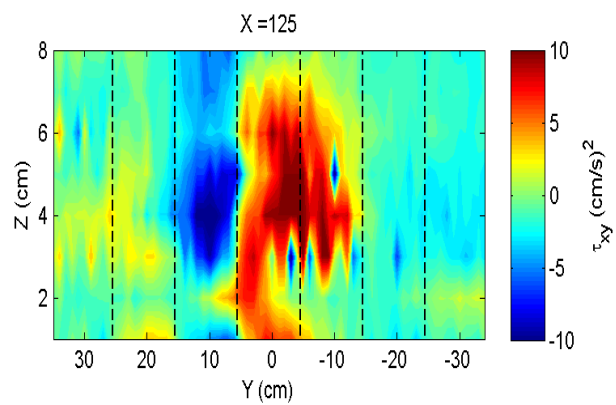
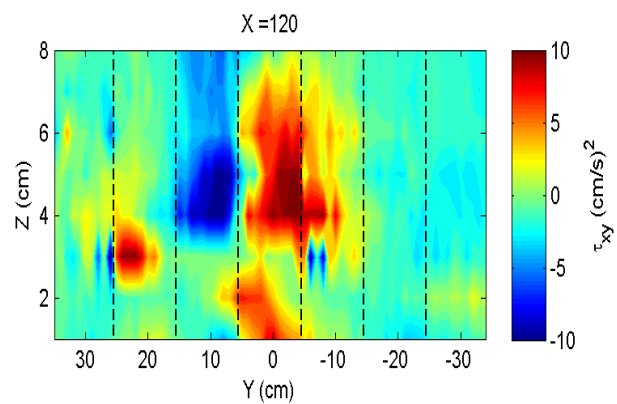
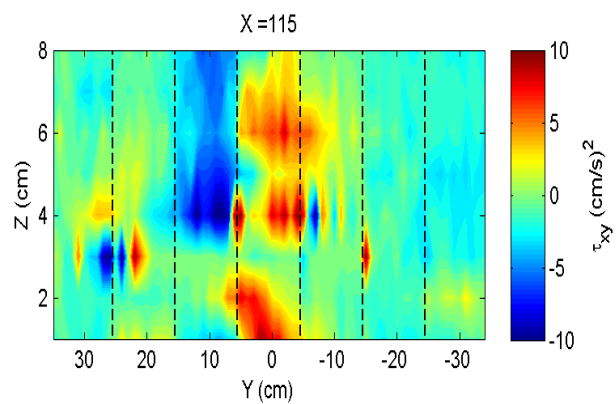
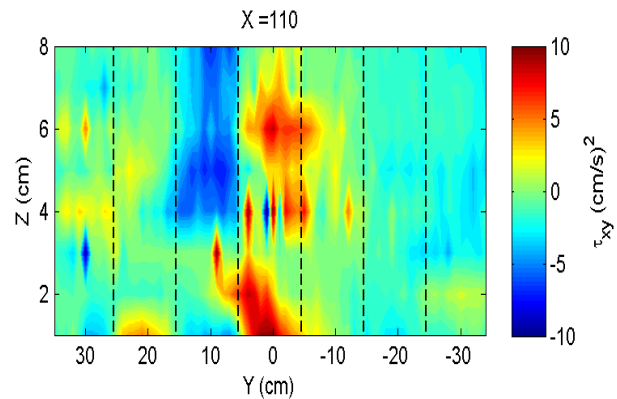
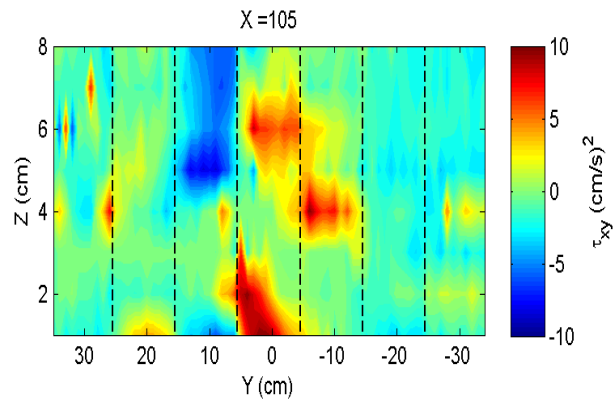
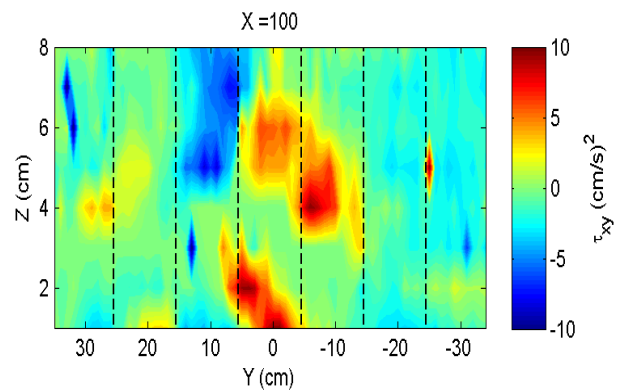
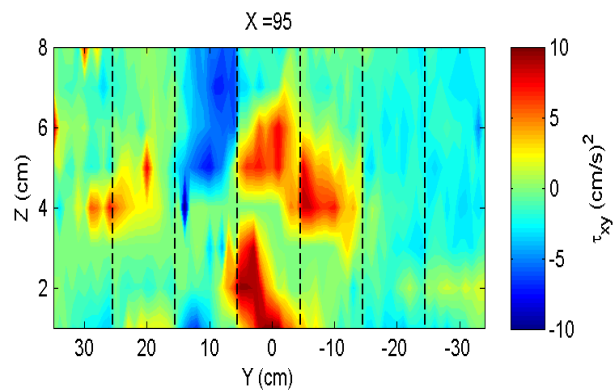
## 11. Reynolds Shear Stresses $\tau_{xy}$ in y and z-Directions

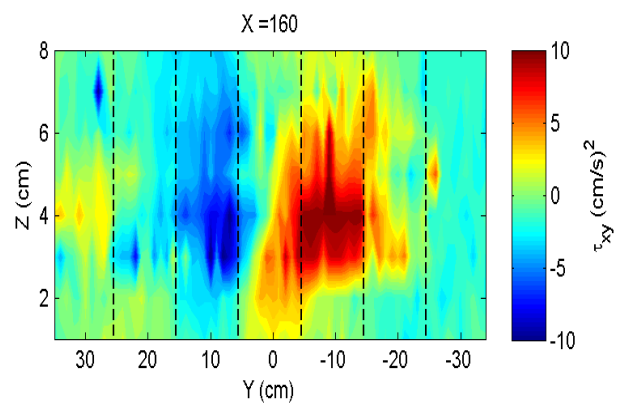
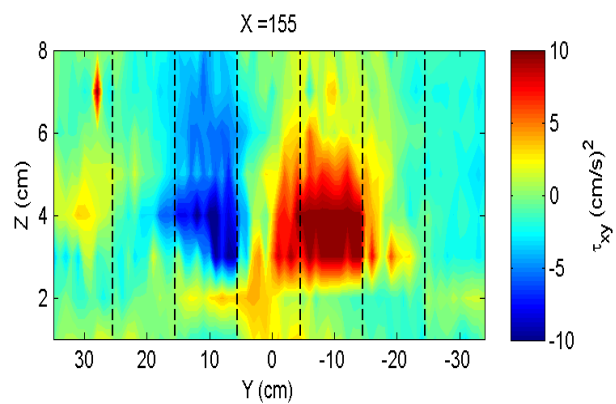
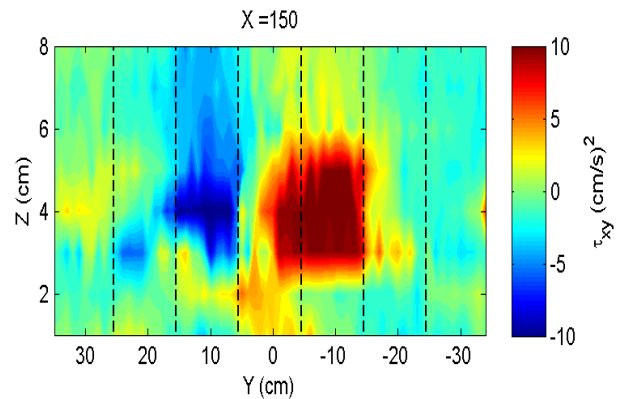
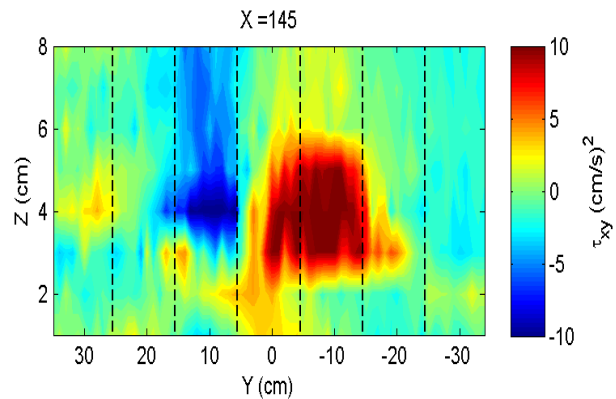
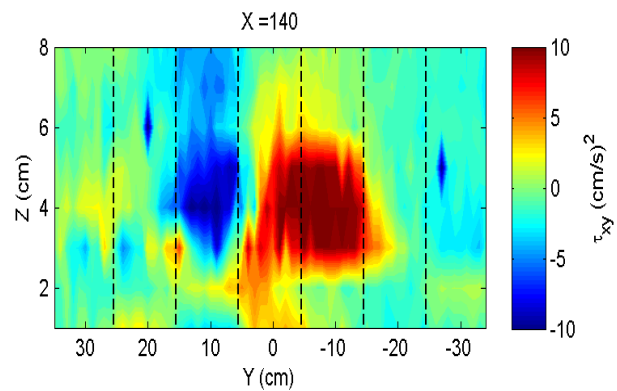
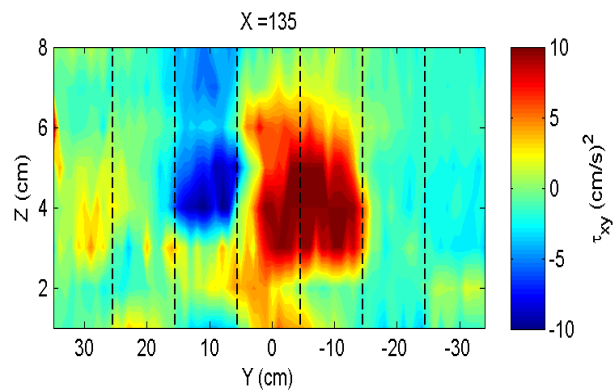




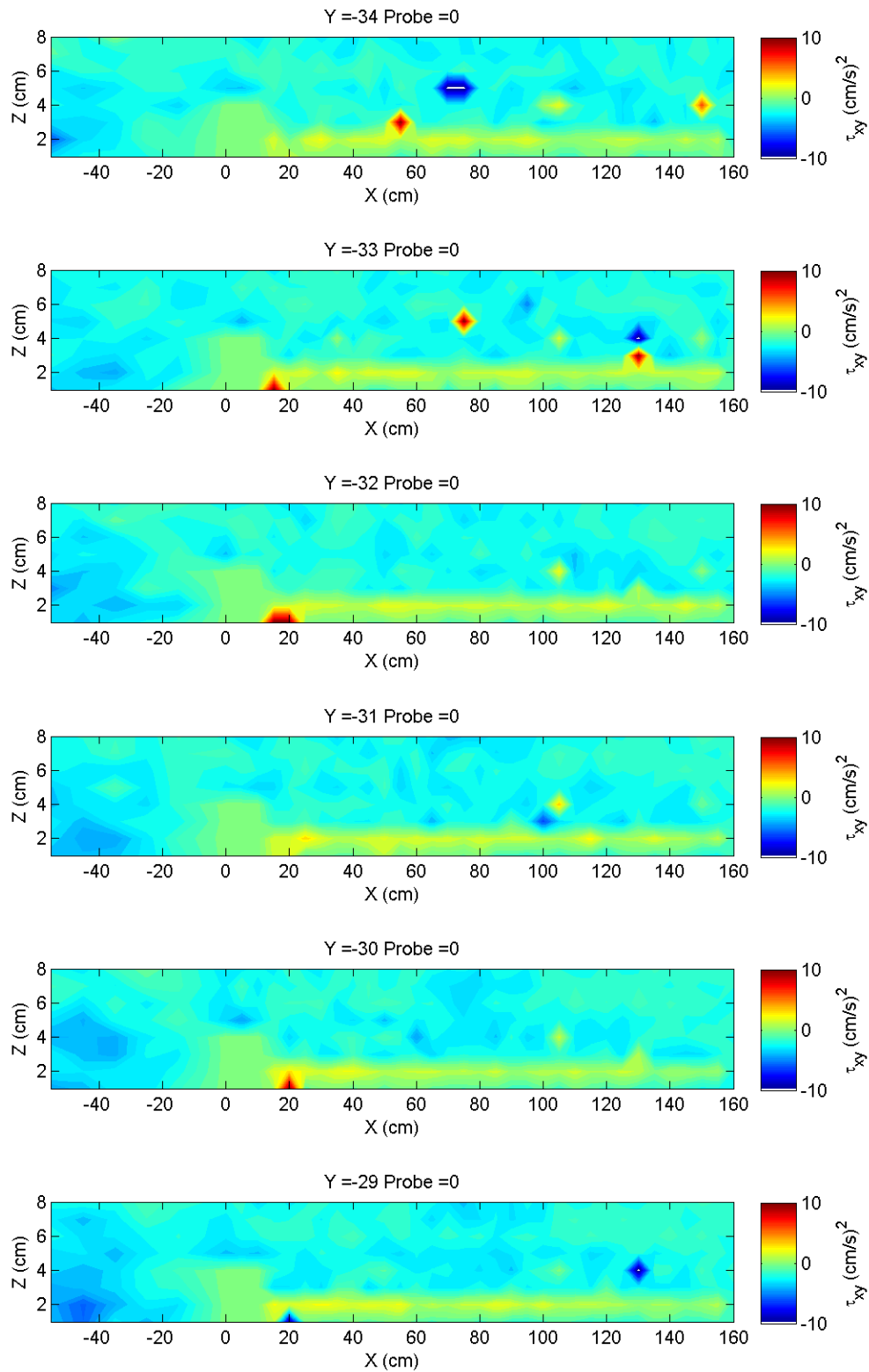


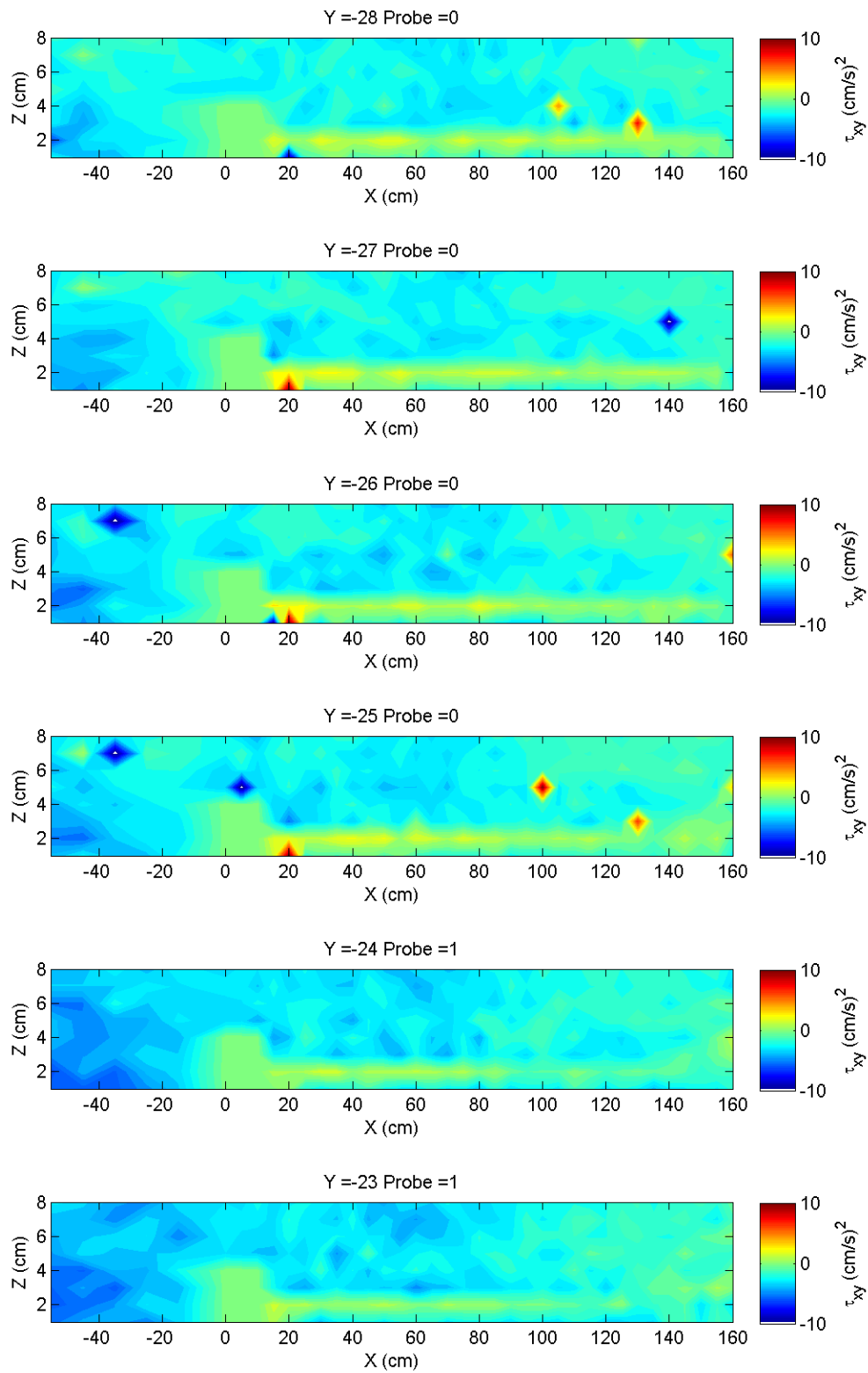


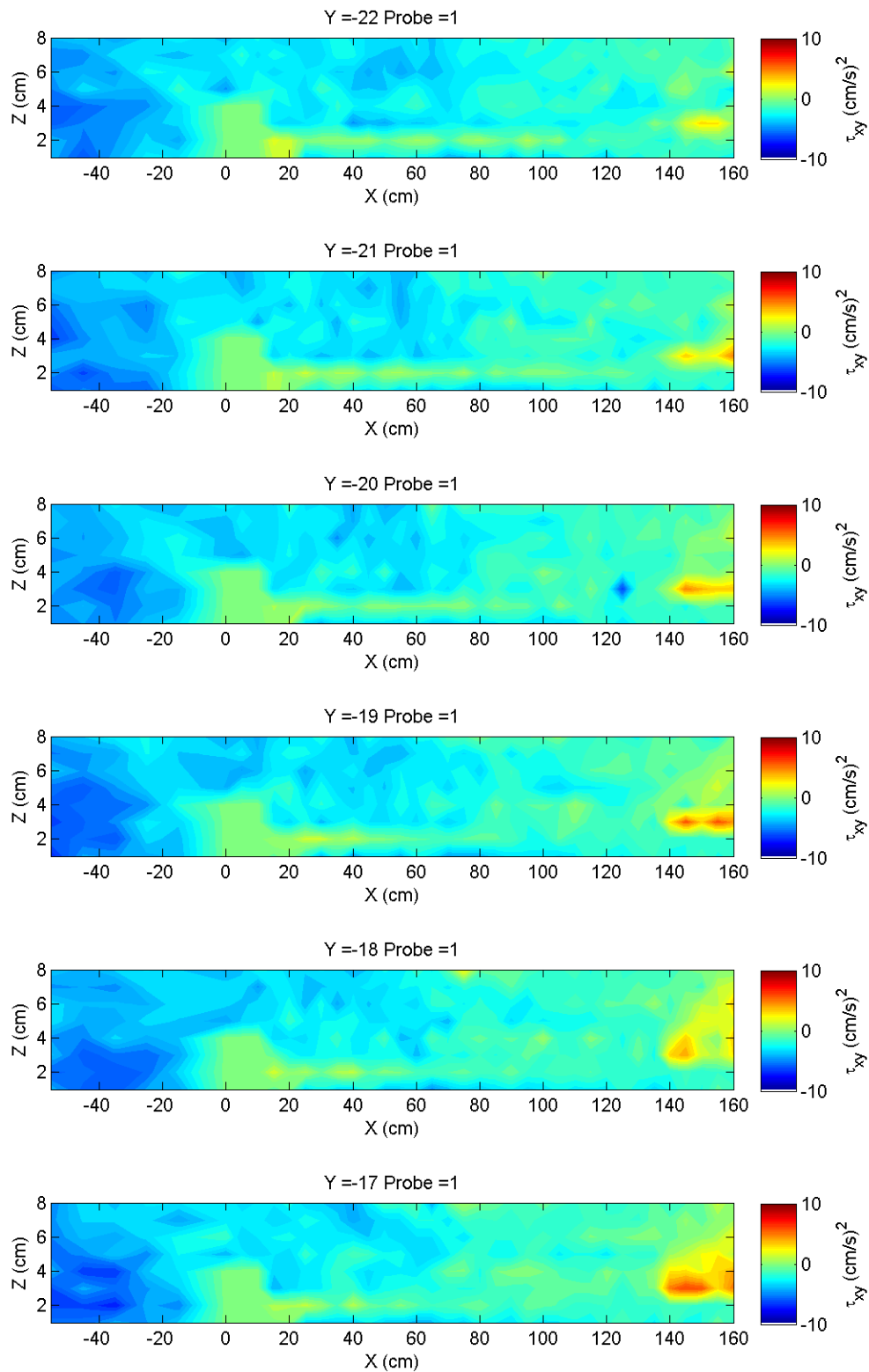


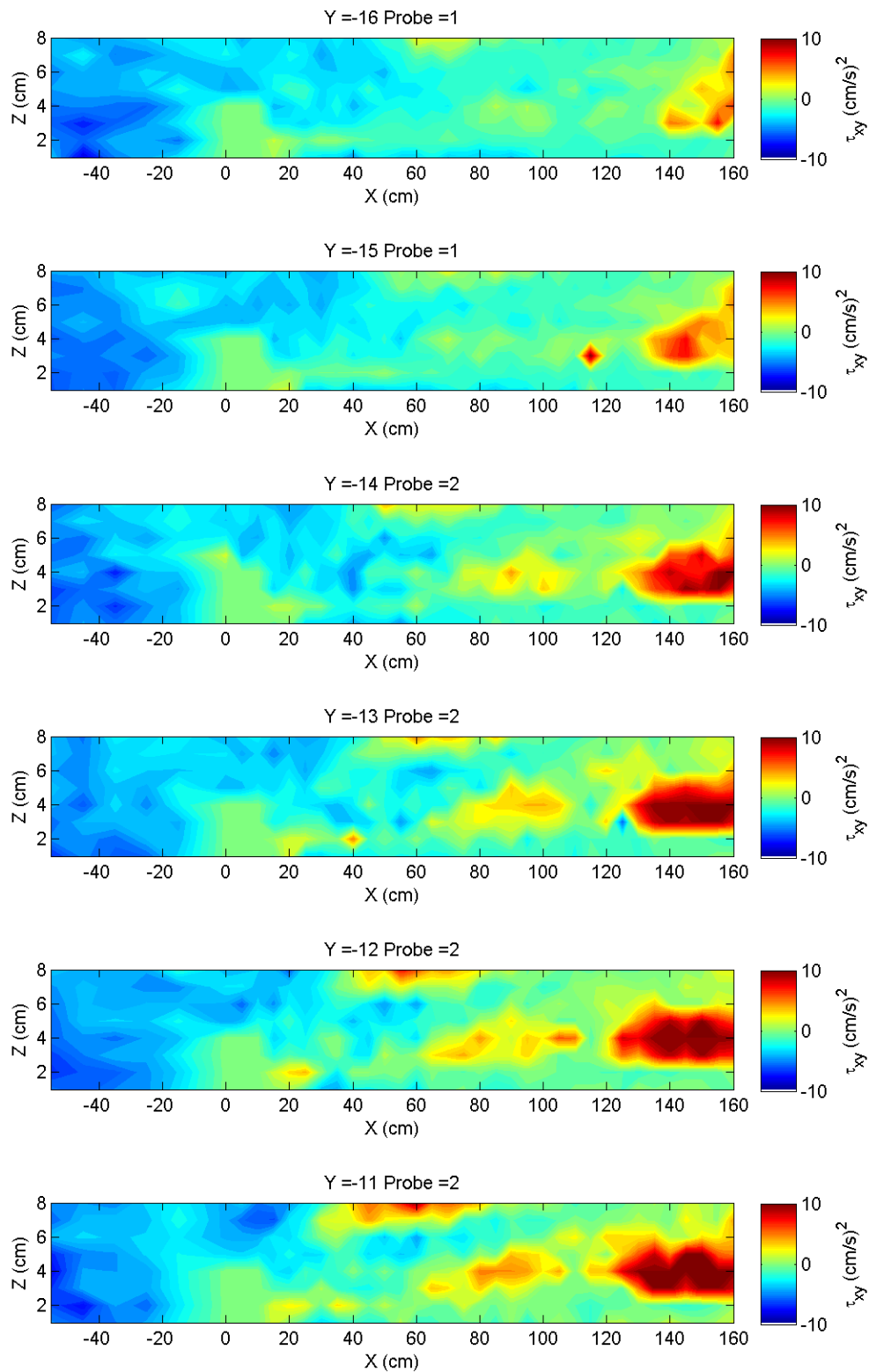


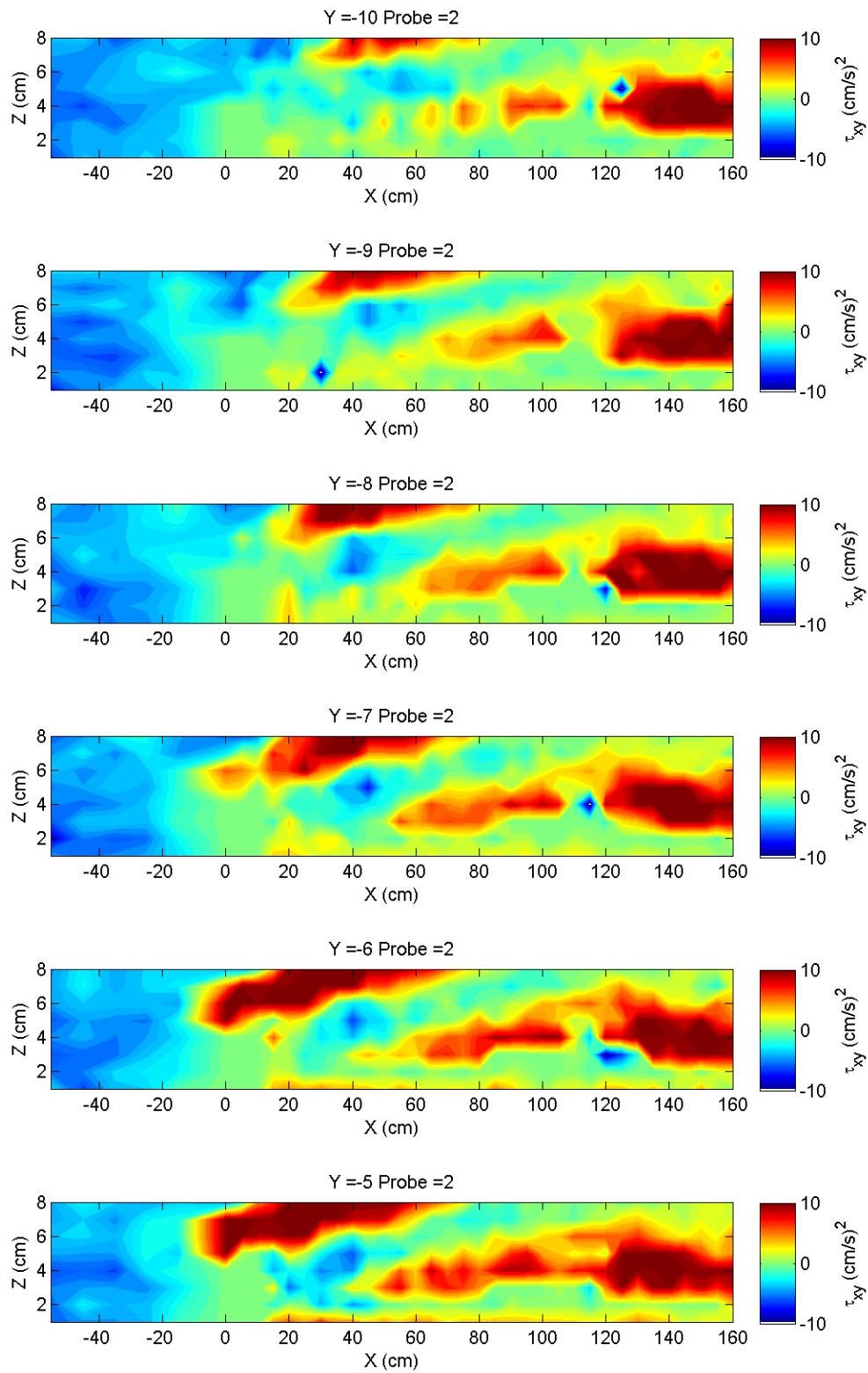
## 12. Reynolds Shear Stresses $\tau_{xy}$ in x and z-Directions



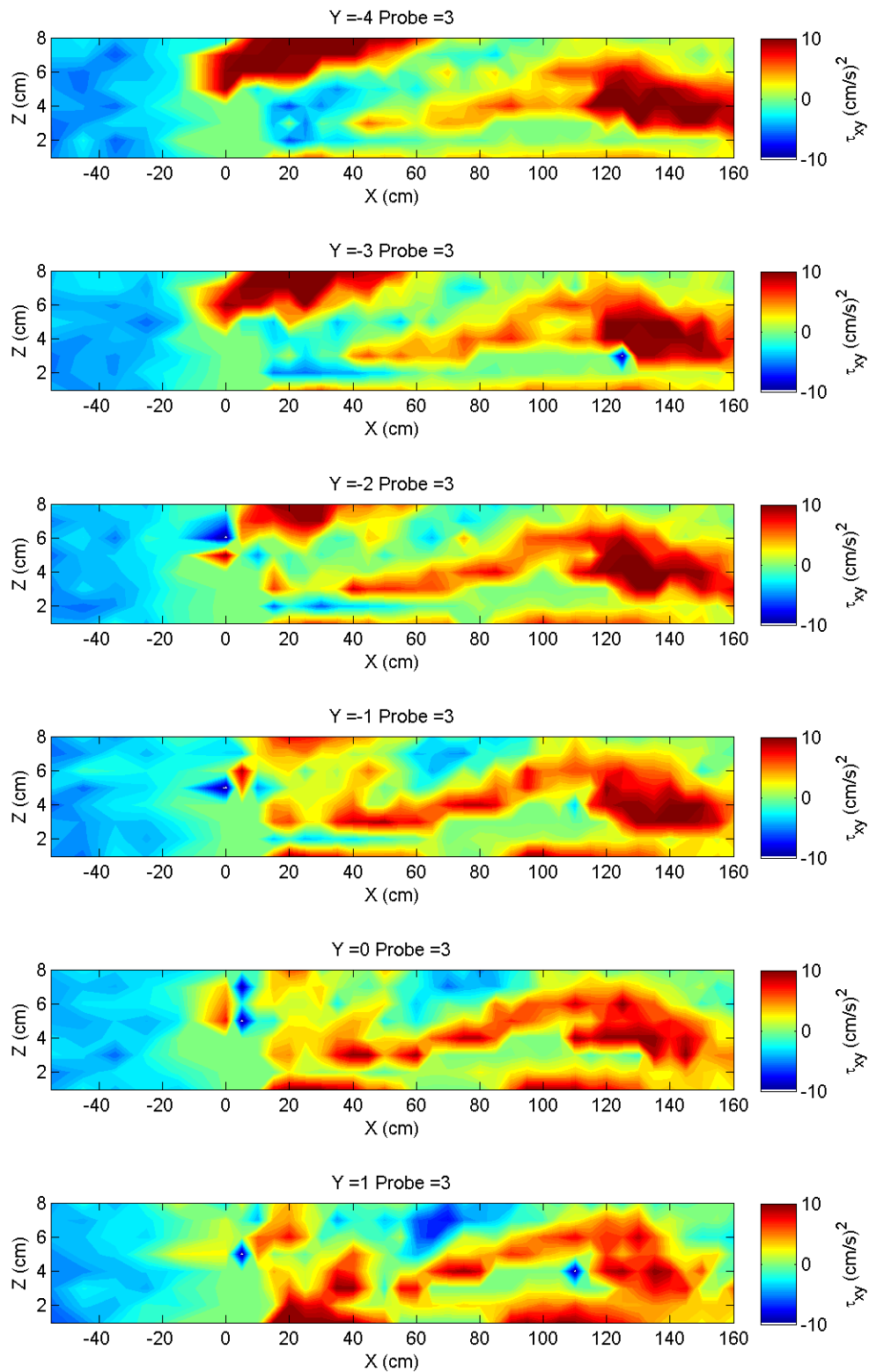


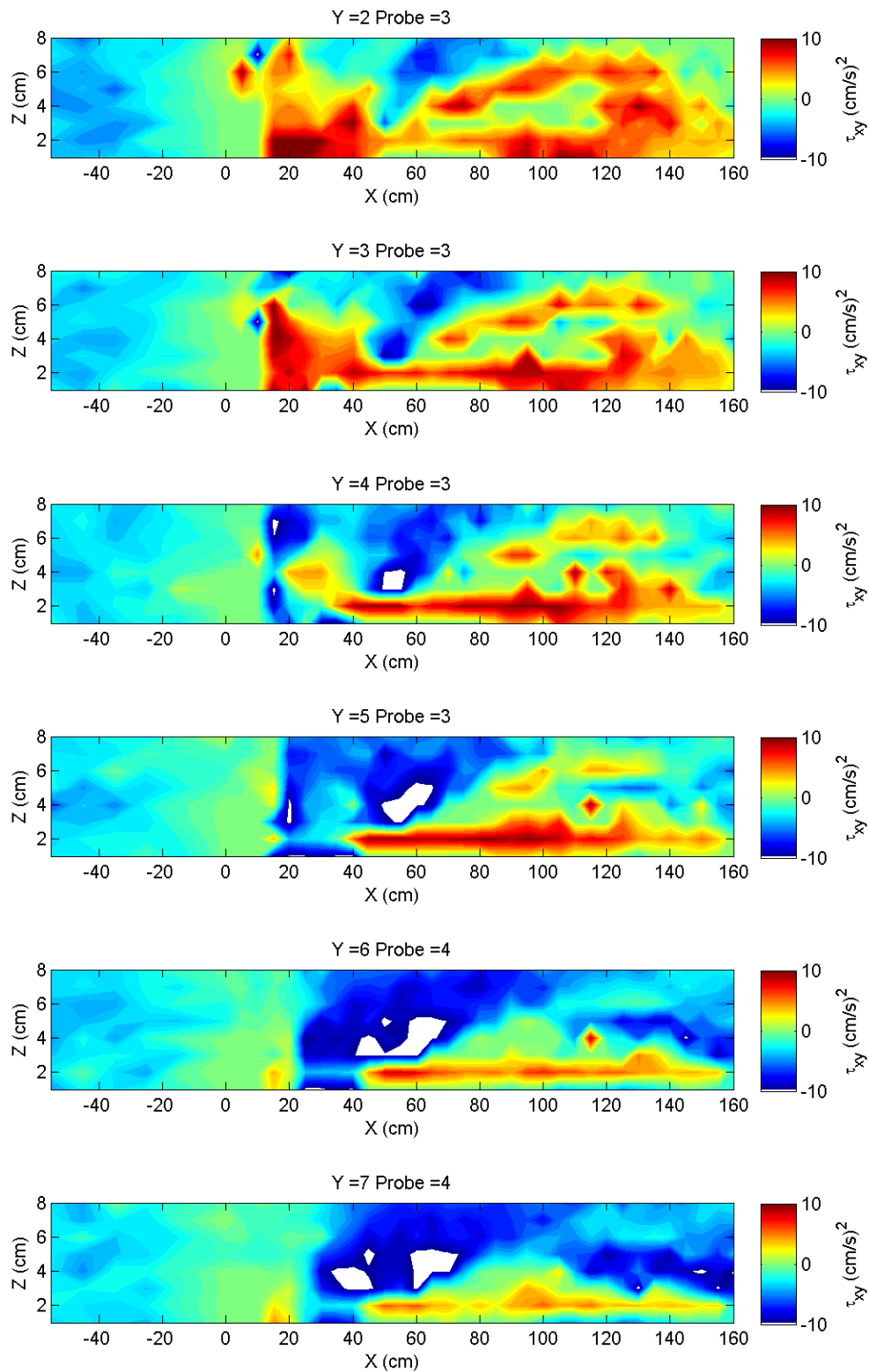


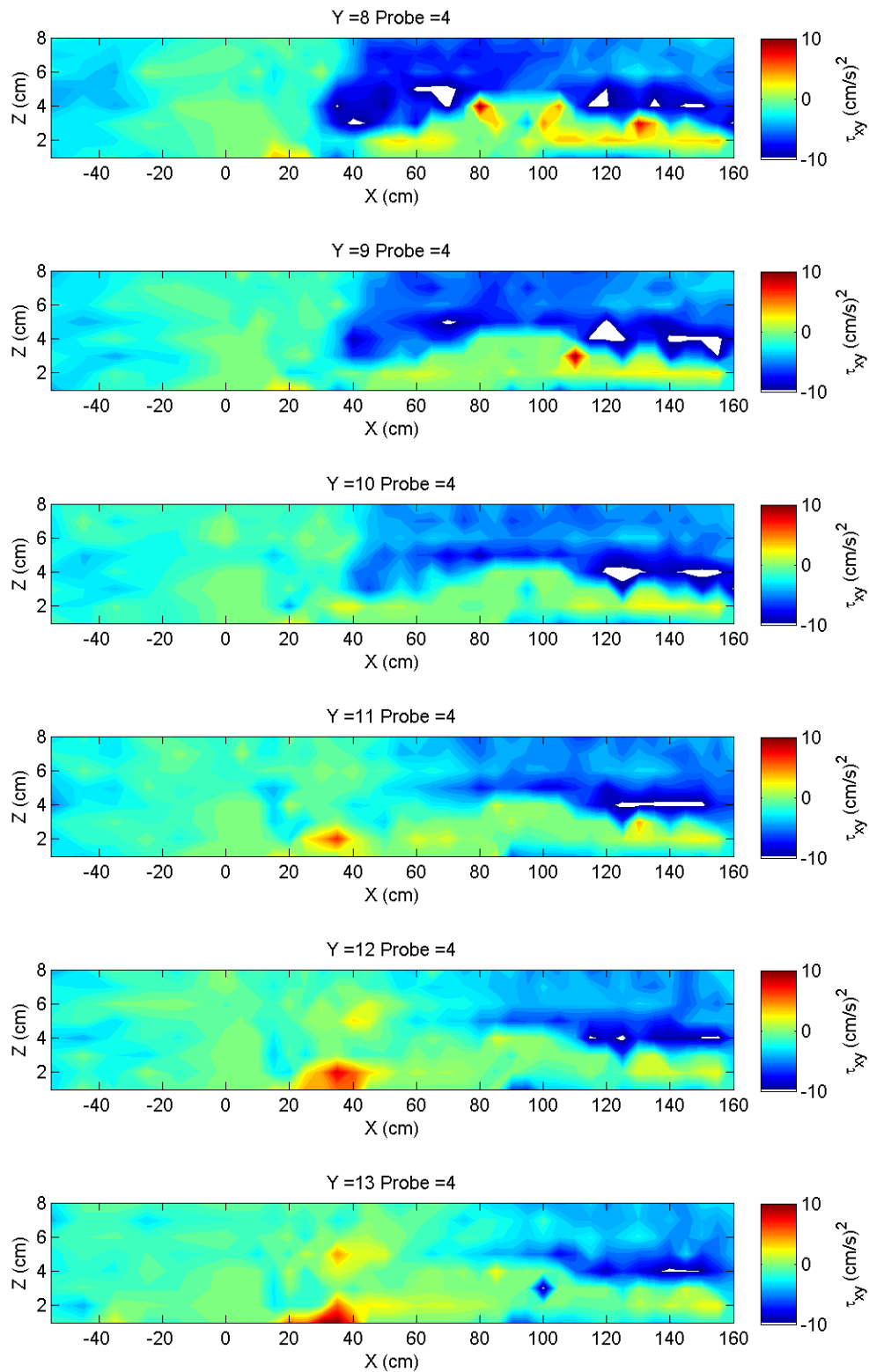


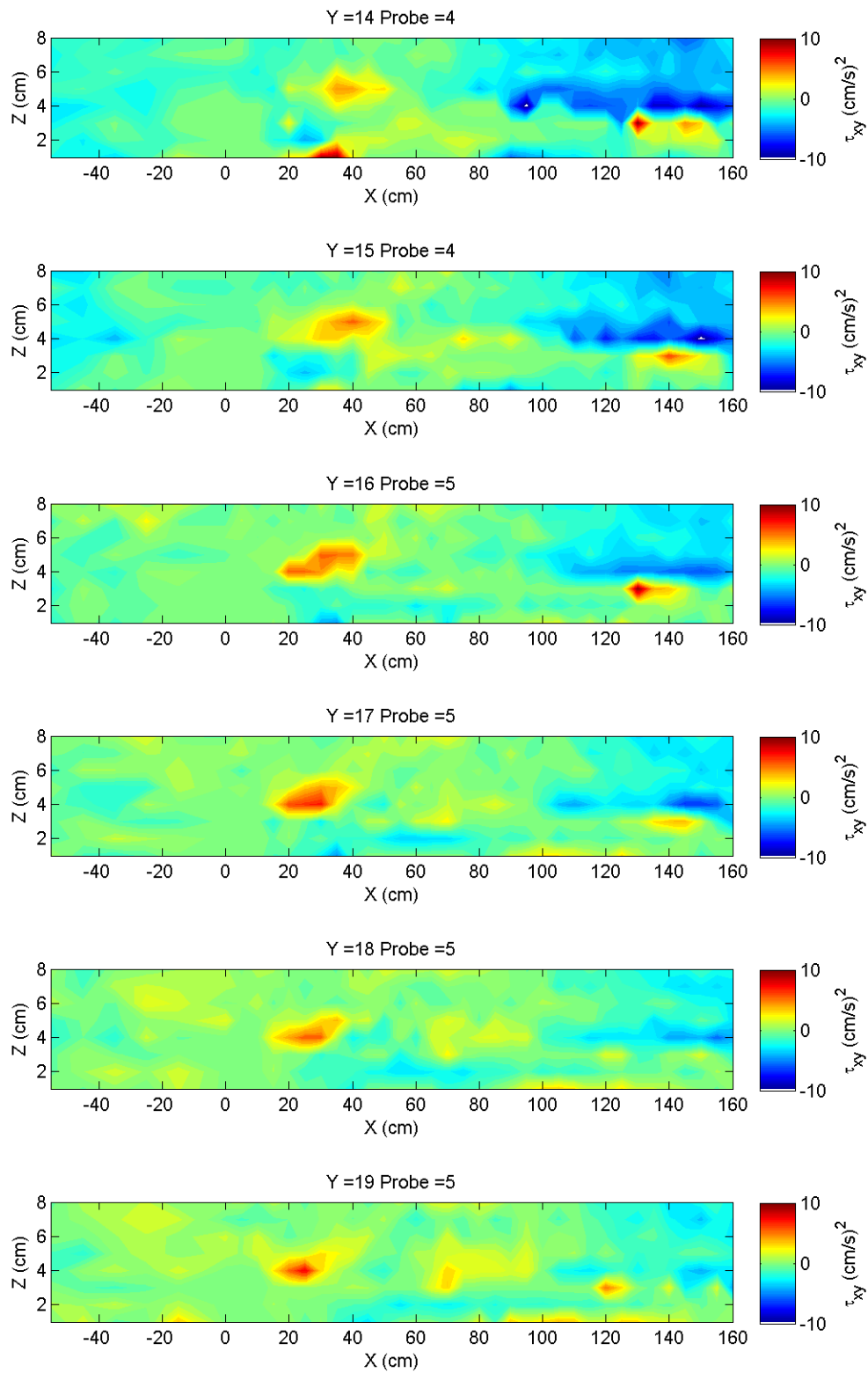


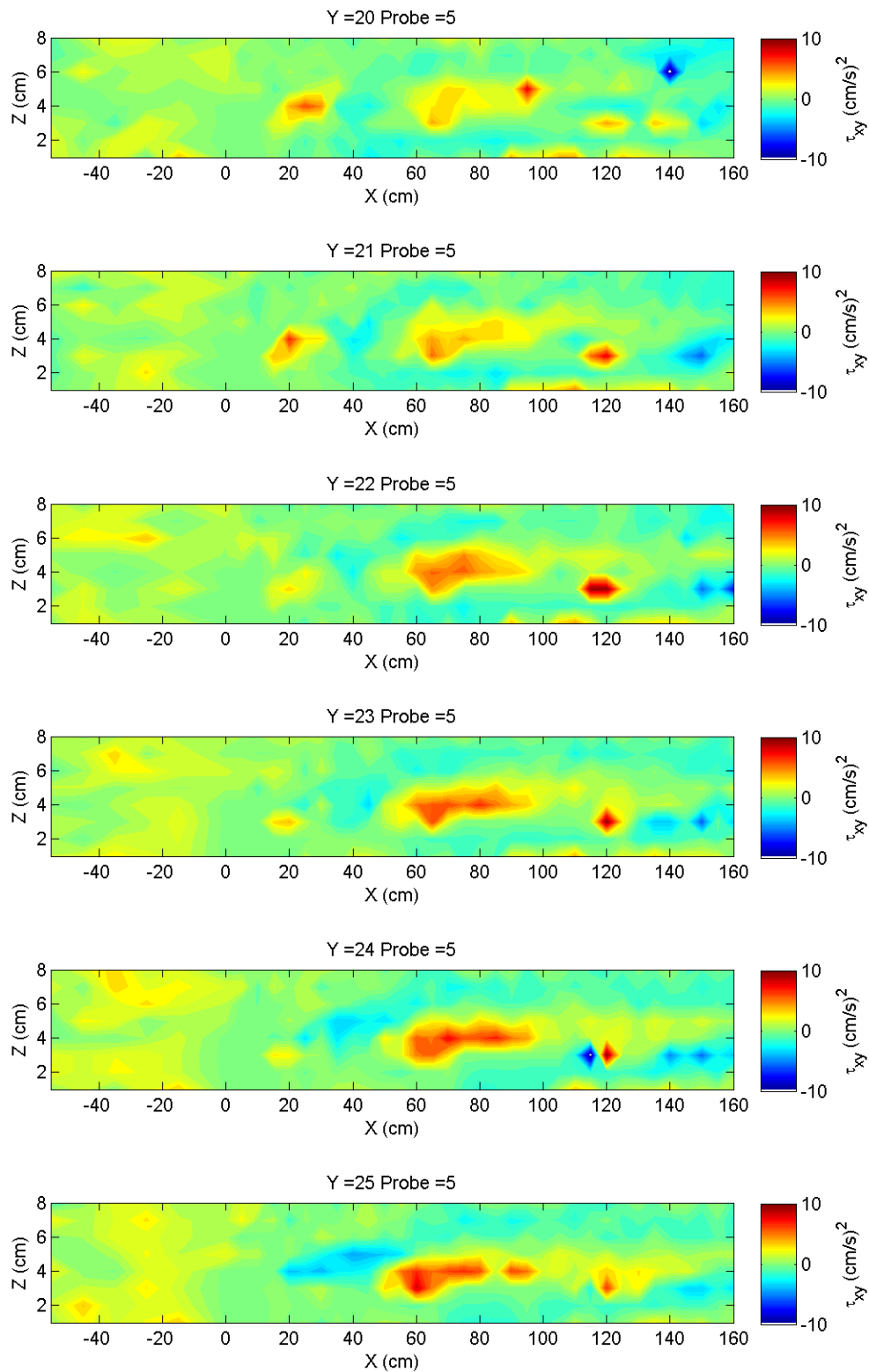


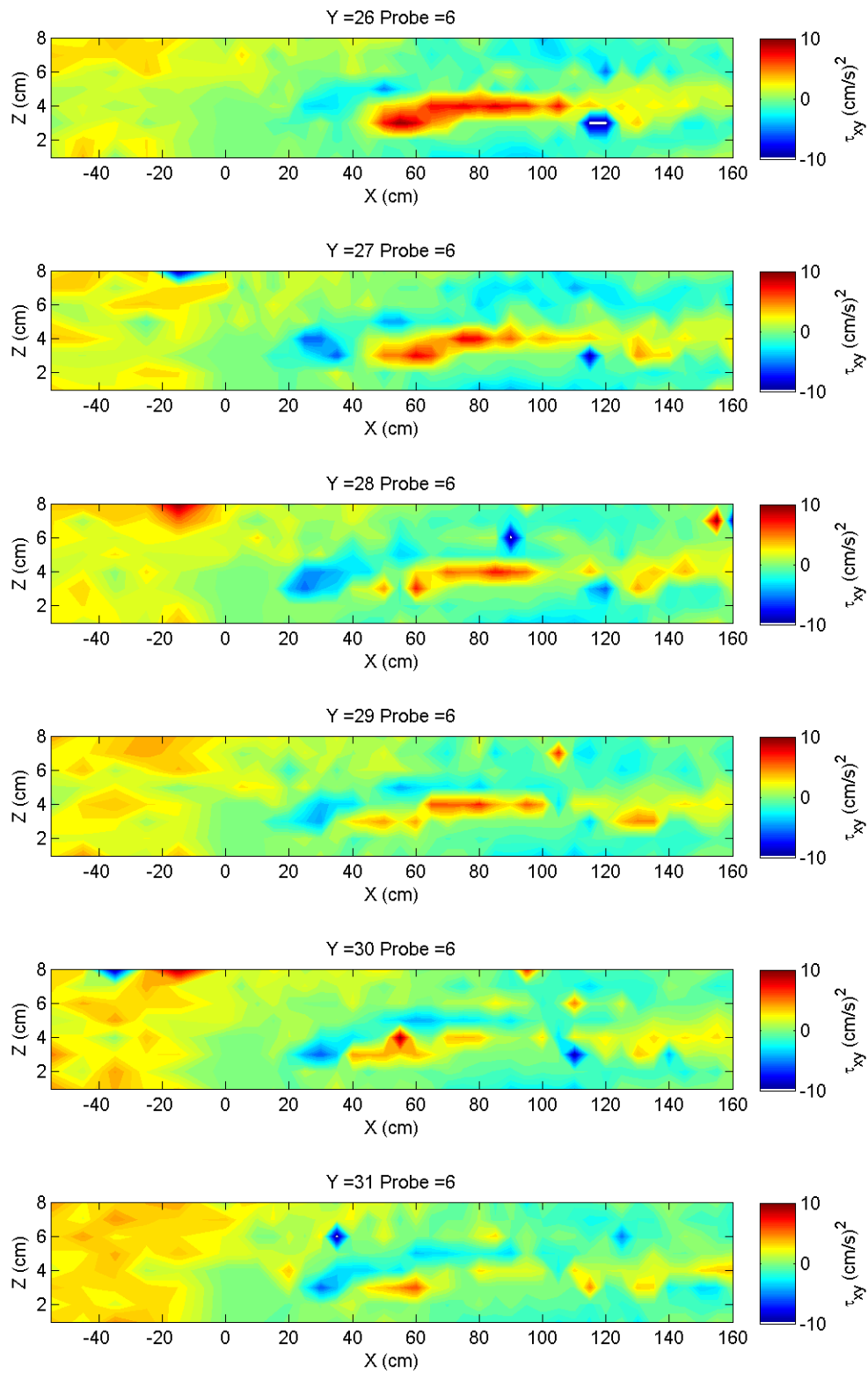


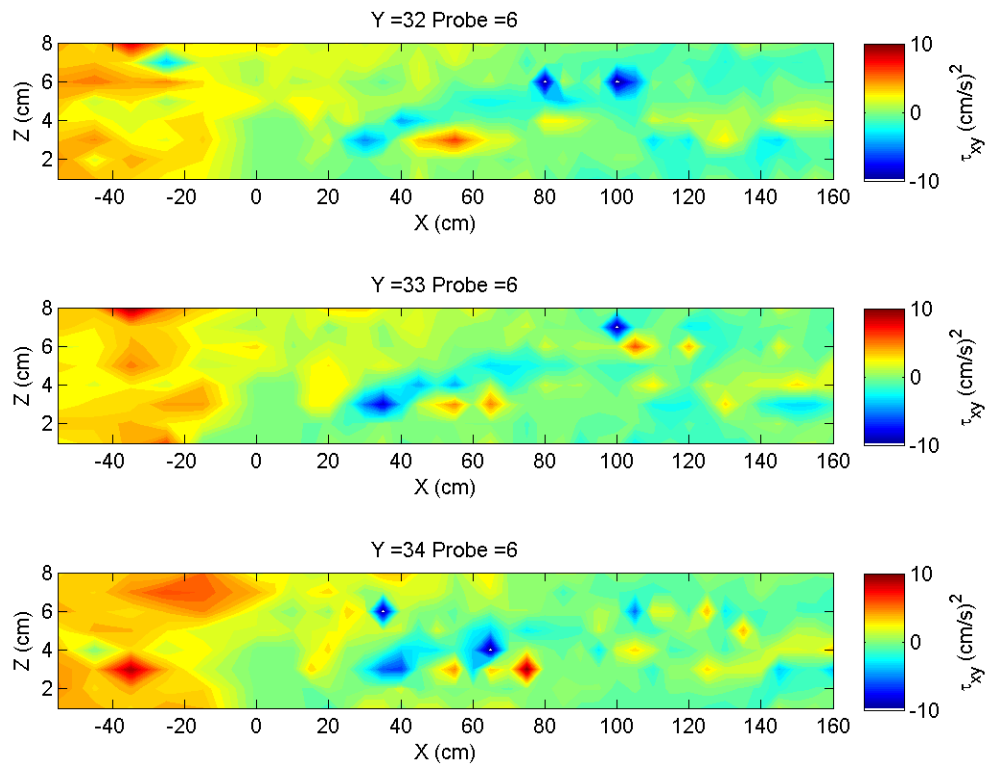






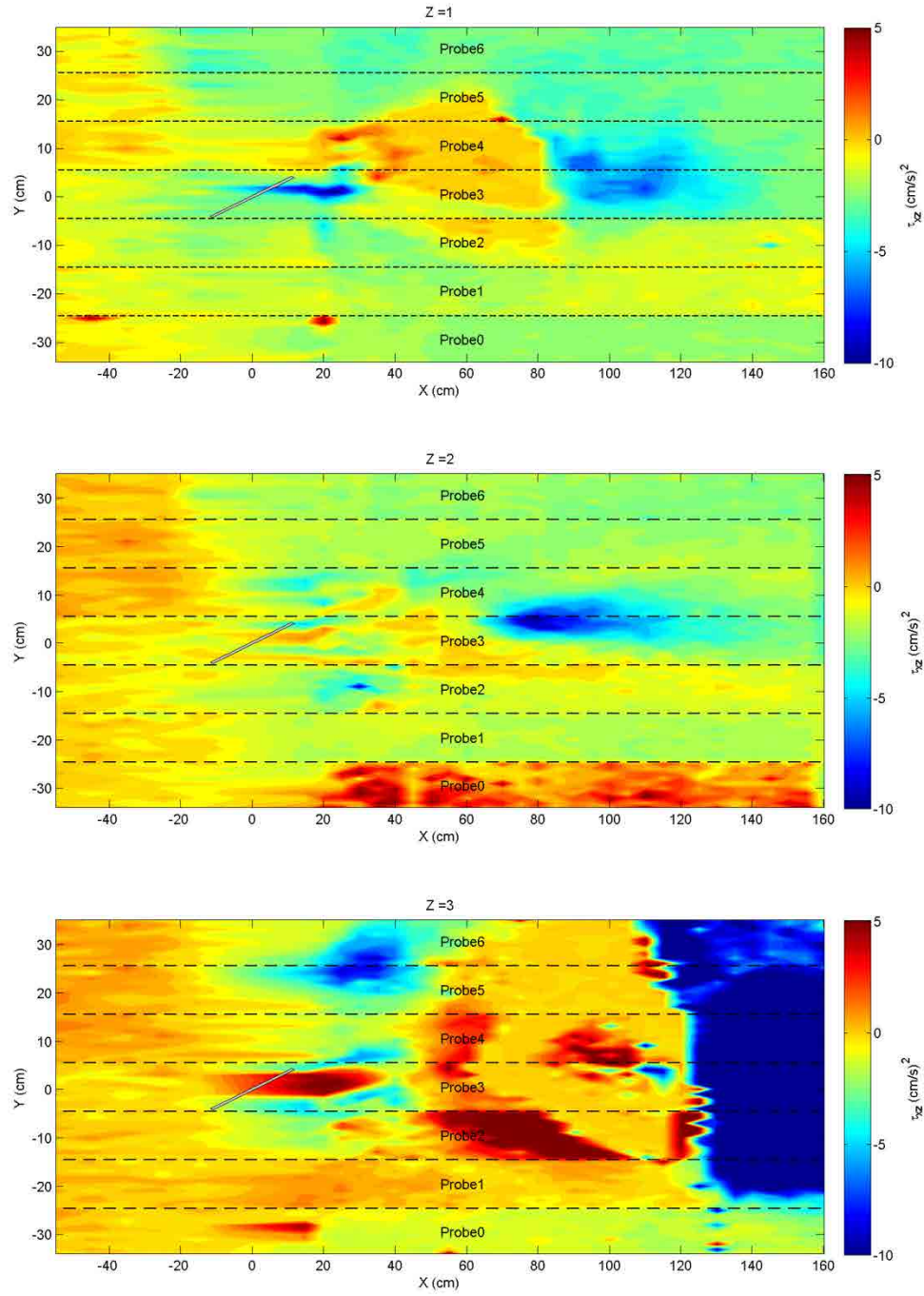




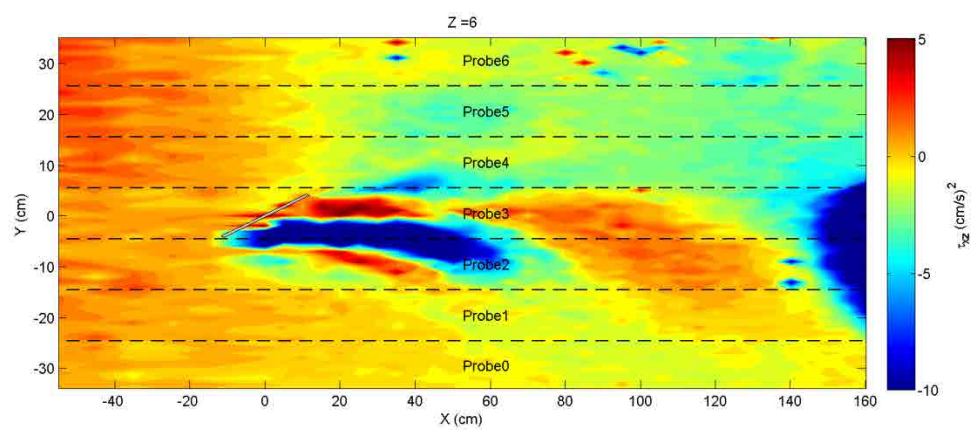
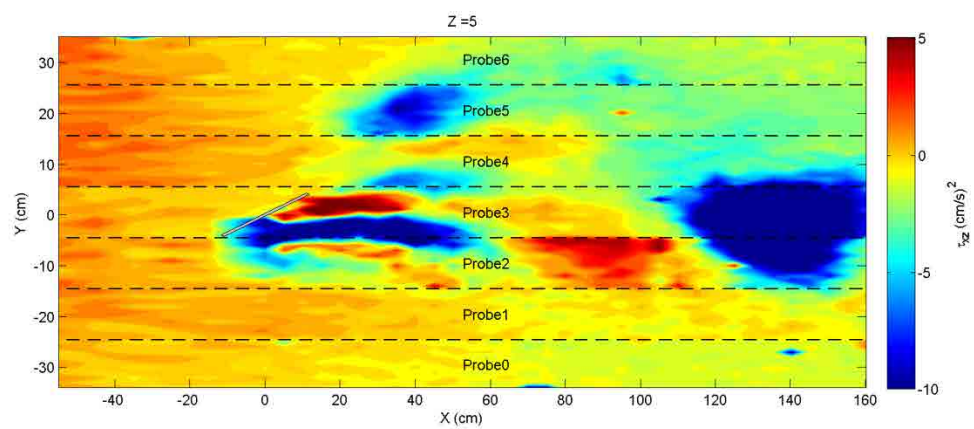
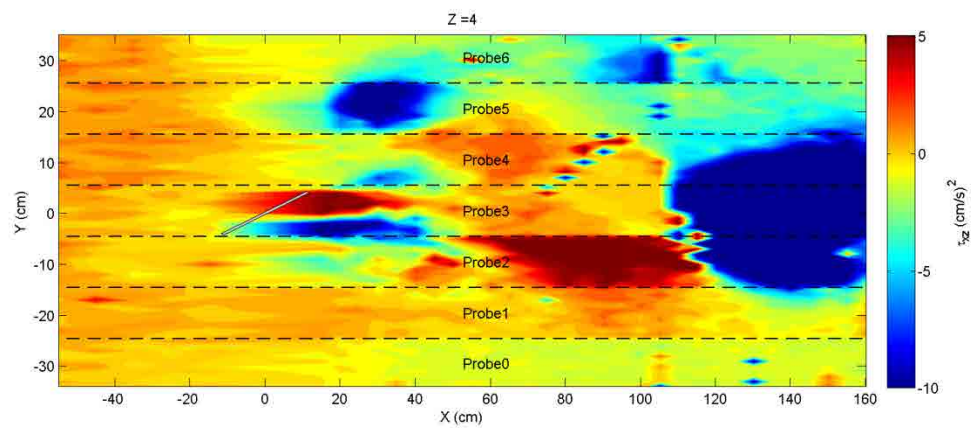


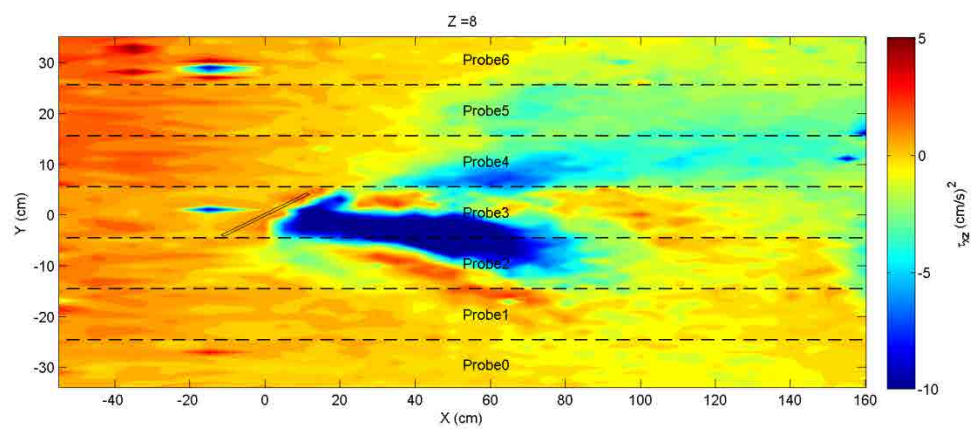
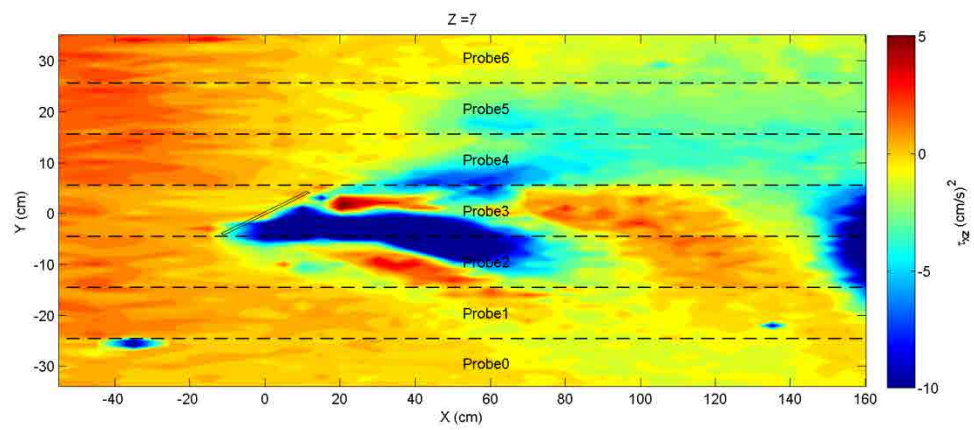


### 13. Reynolds Shear Stresses $\tau_{xz}$ in x and y-Directions

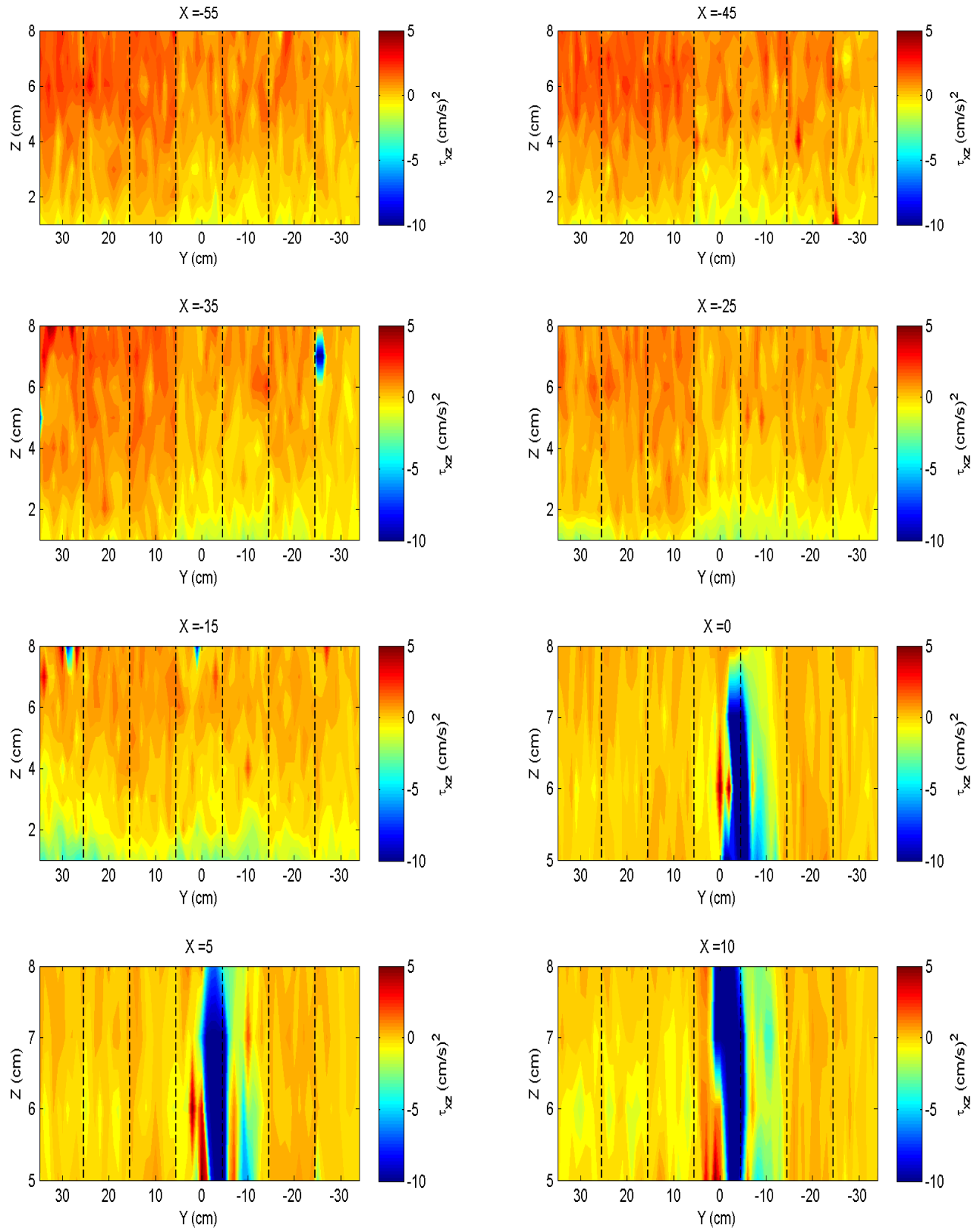


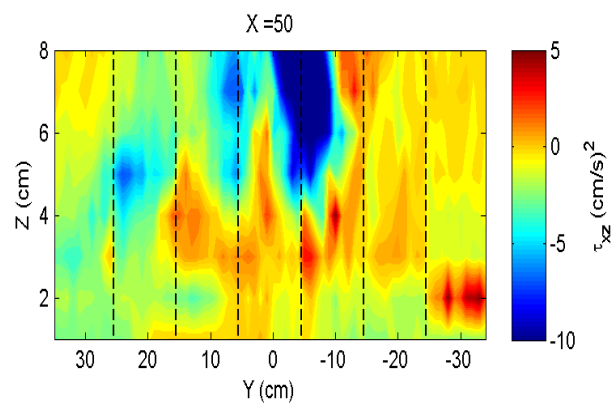
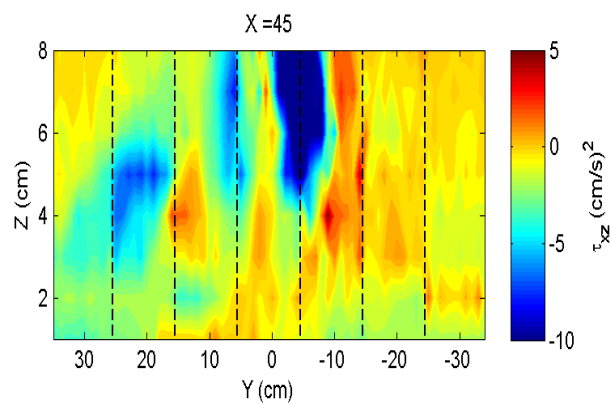
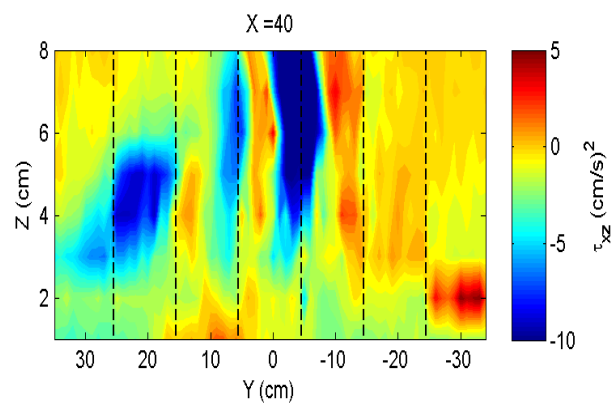
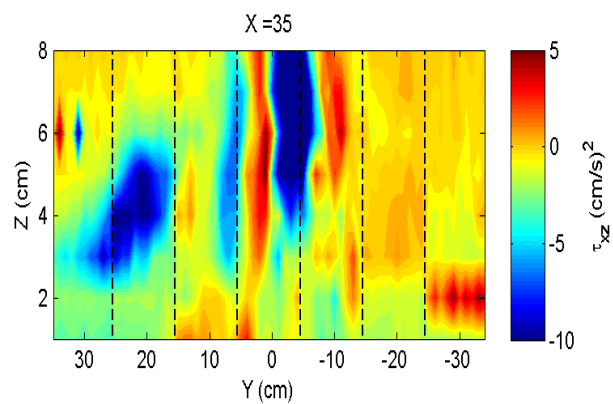
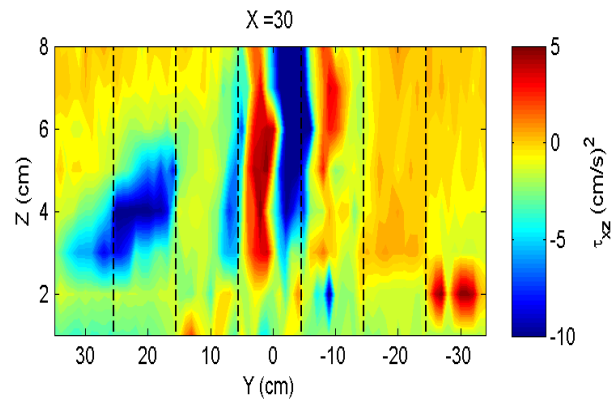
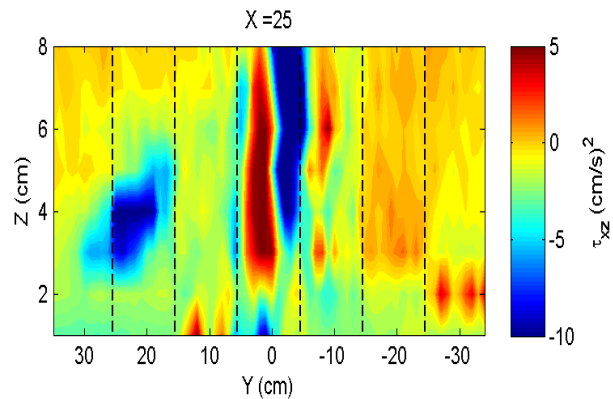
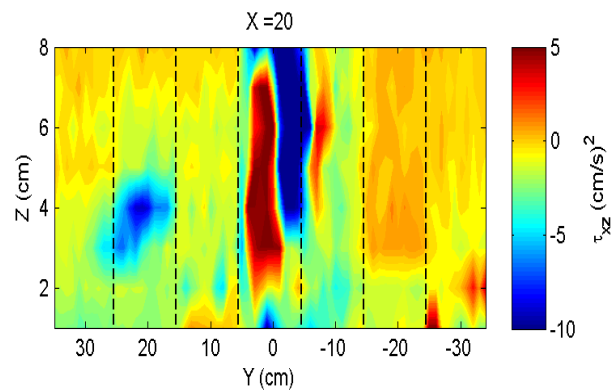
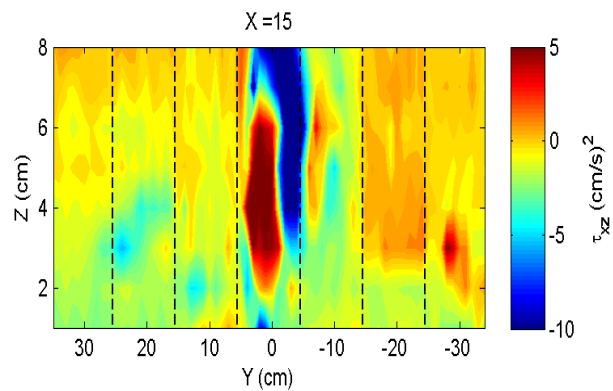


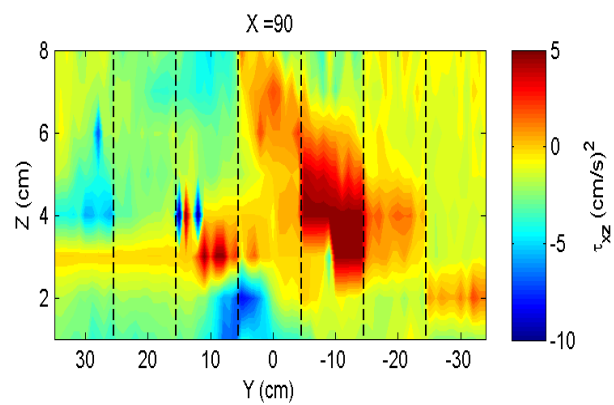
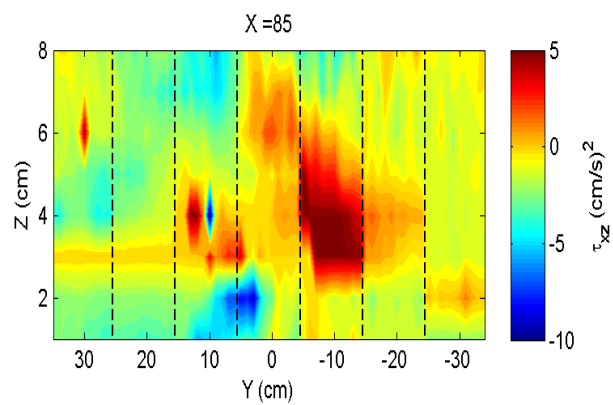
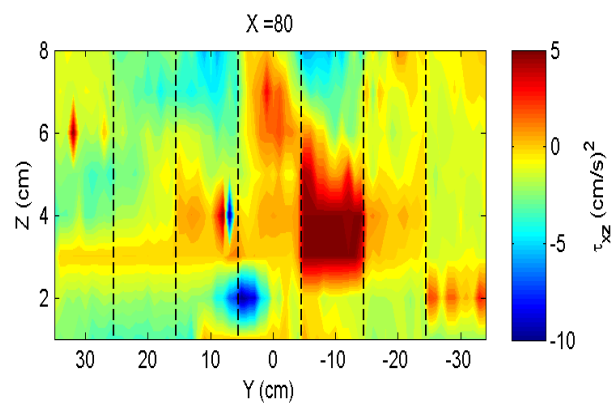
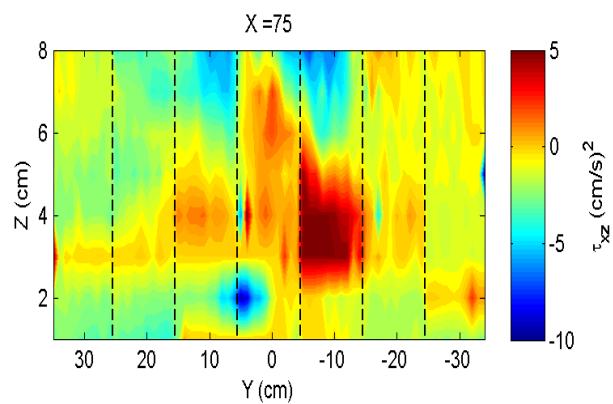
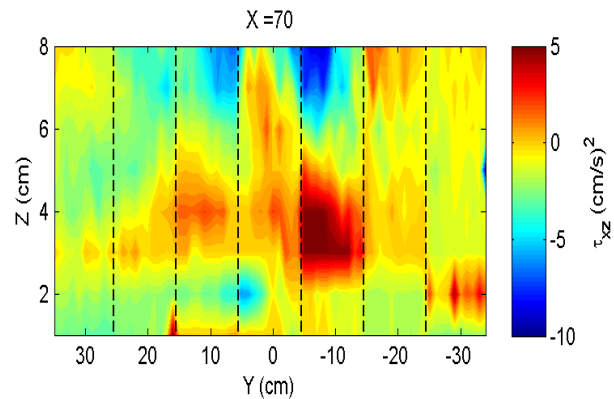
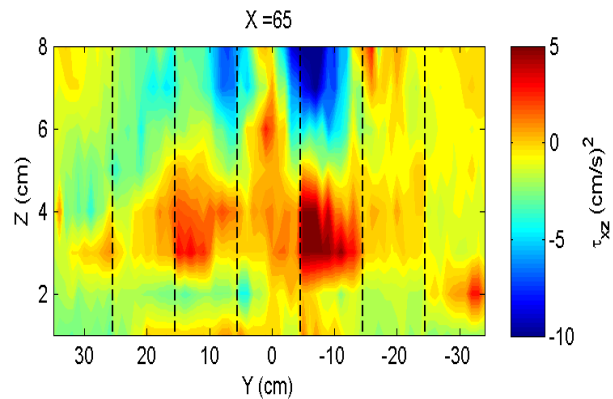
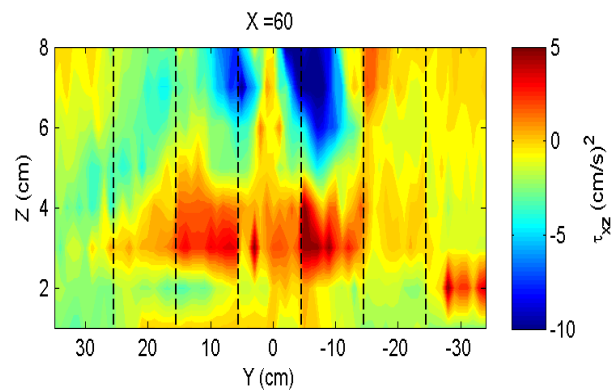
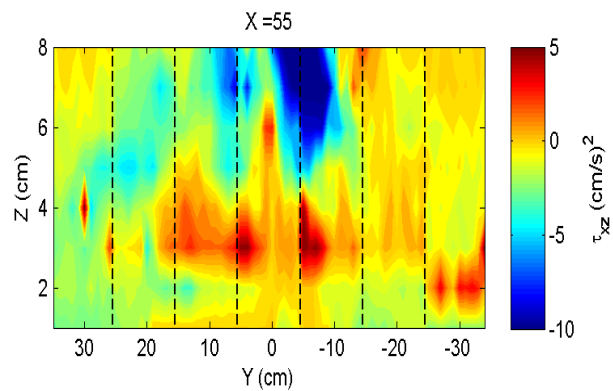




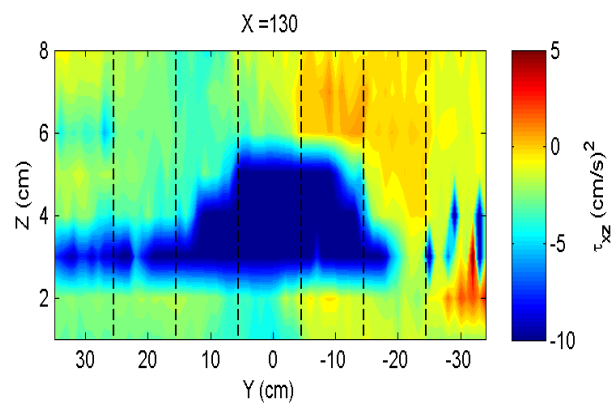
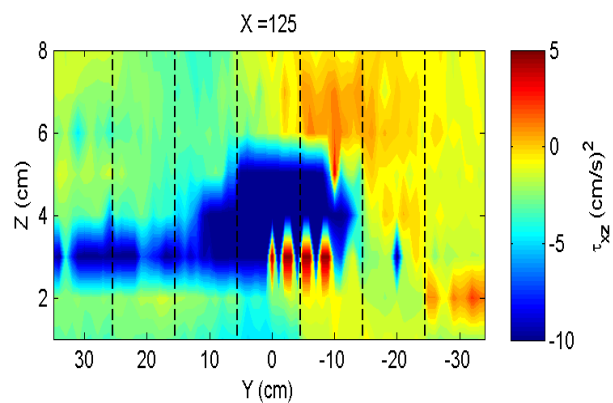
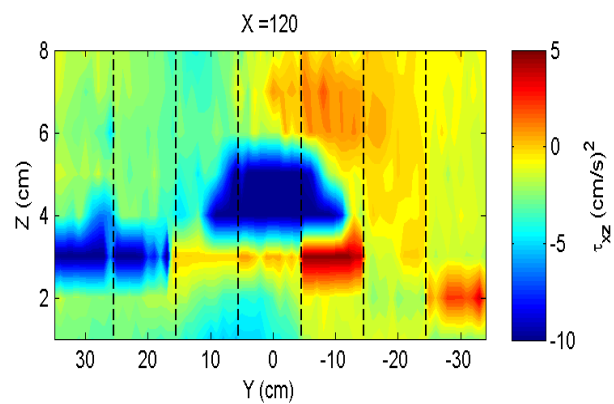
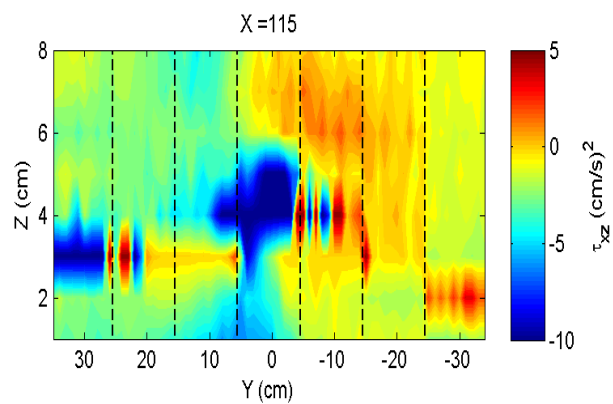
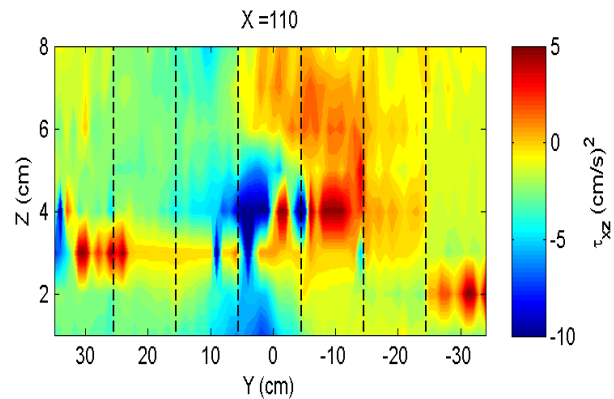
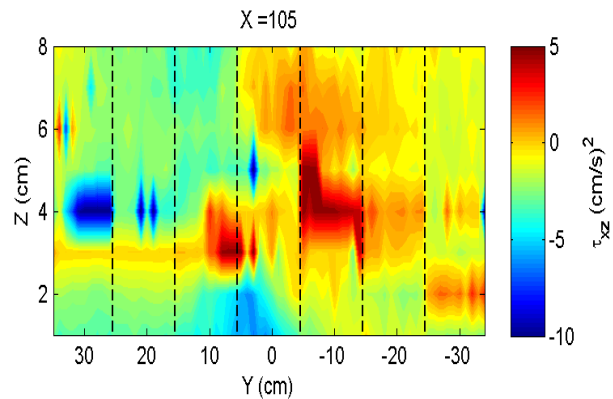
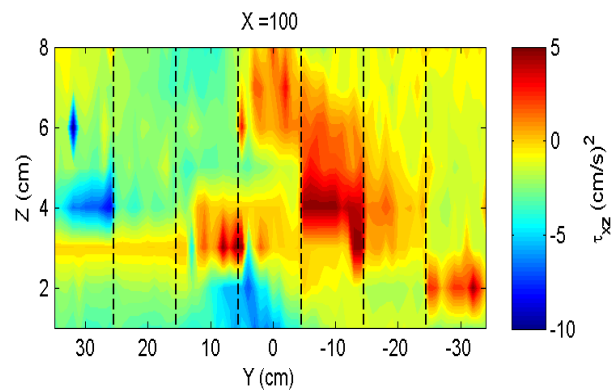
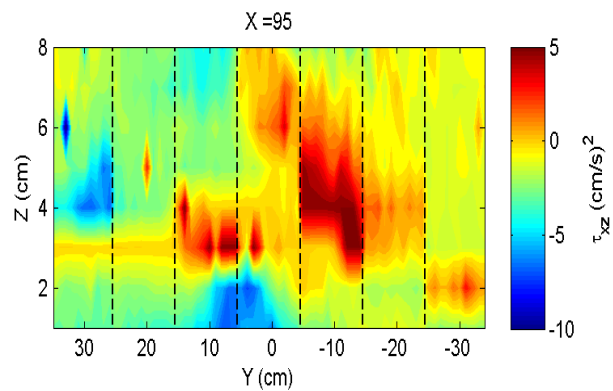
# 14. Reynolds Shear Stresses $\tau_{xz}$ in y and z-Directions

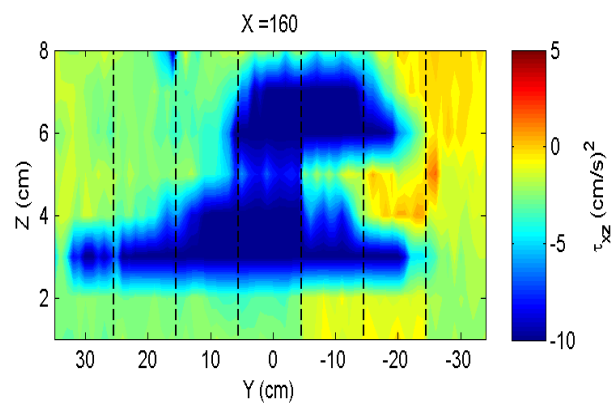
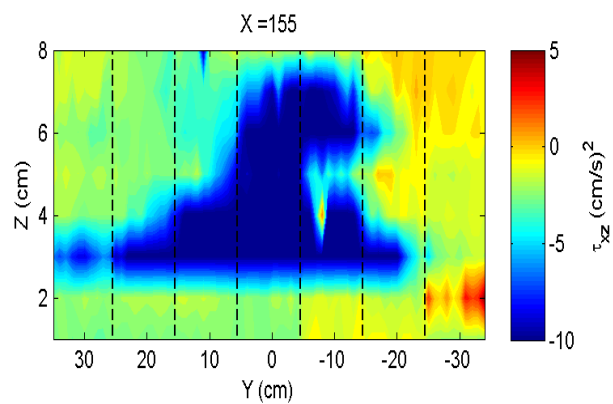
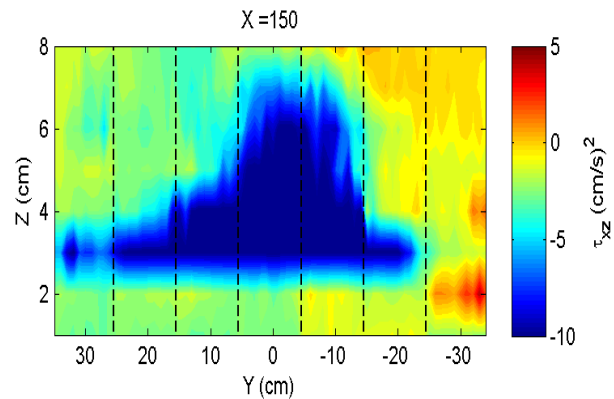
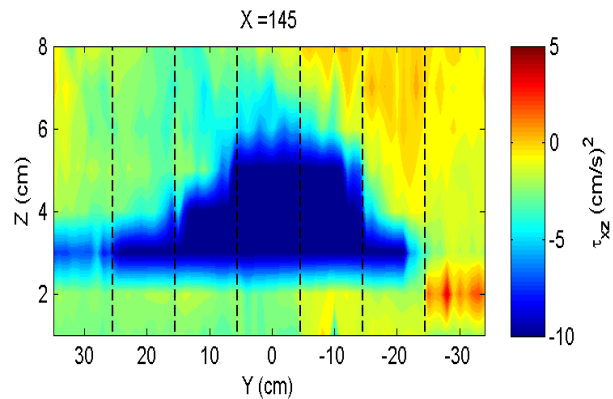
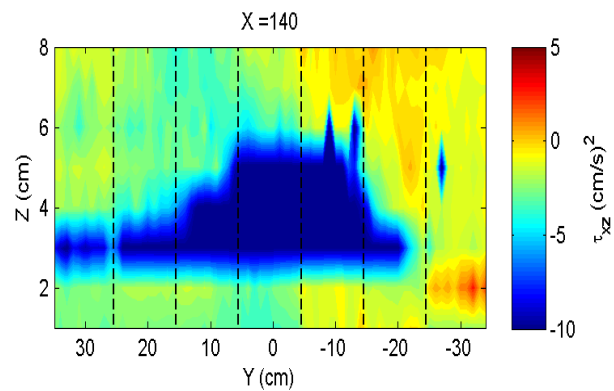
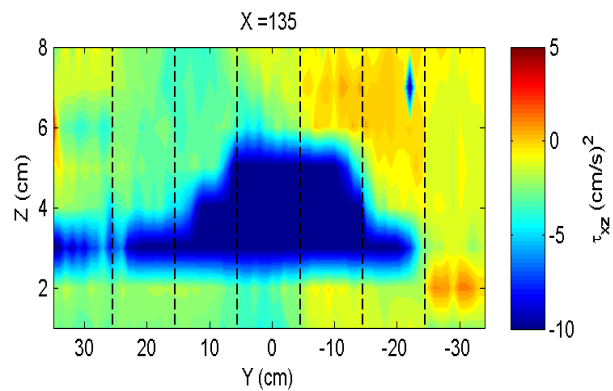




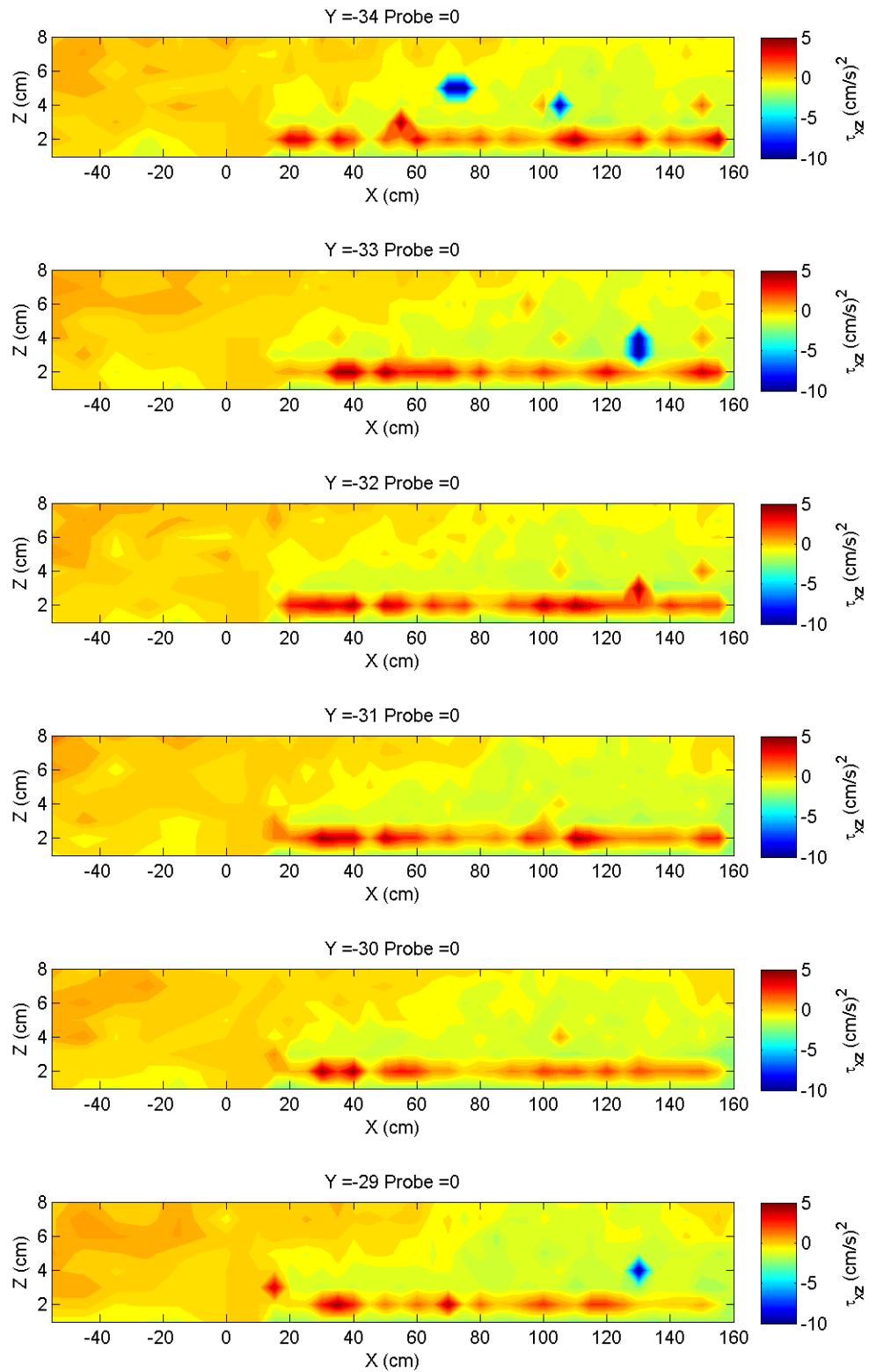




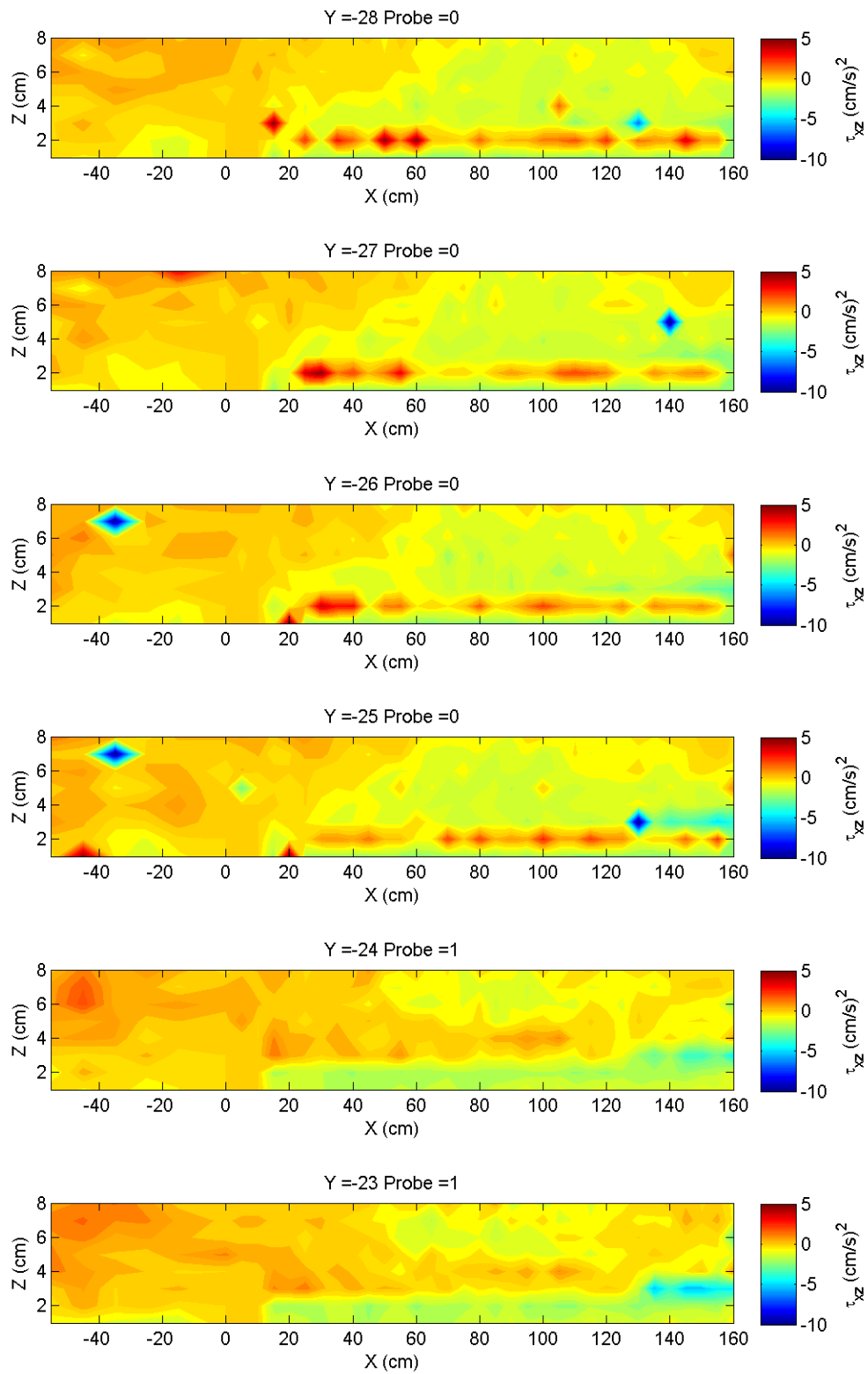


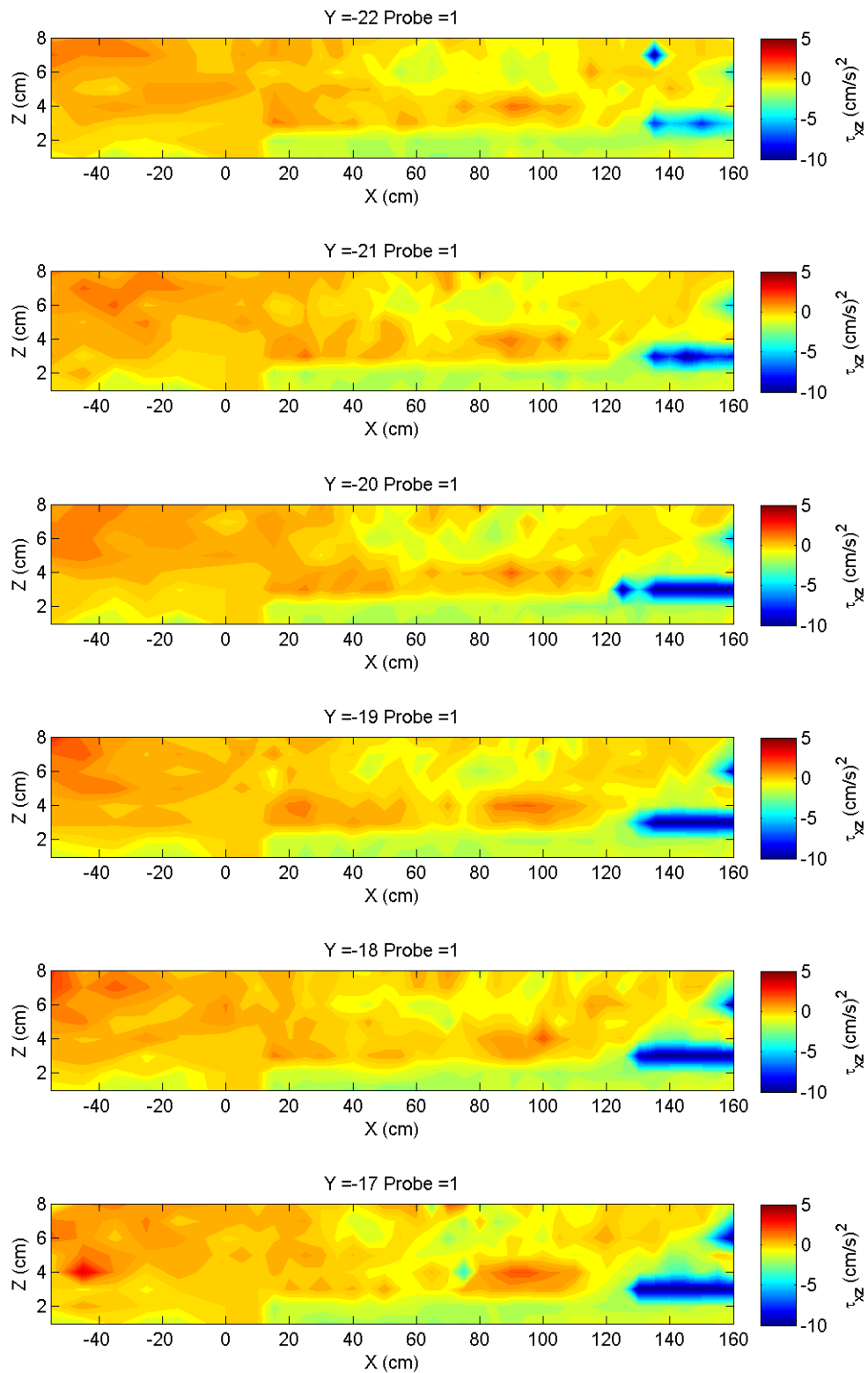


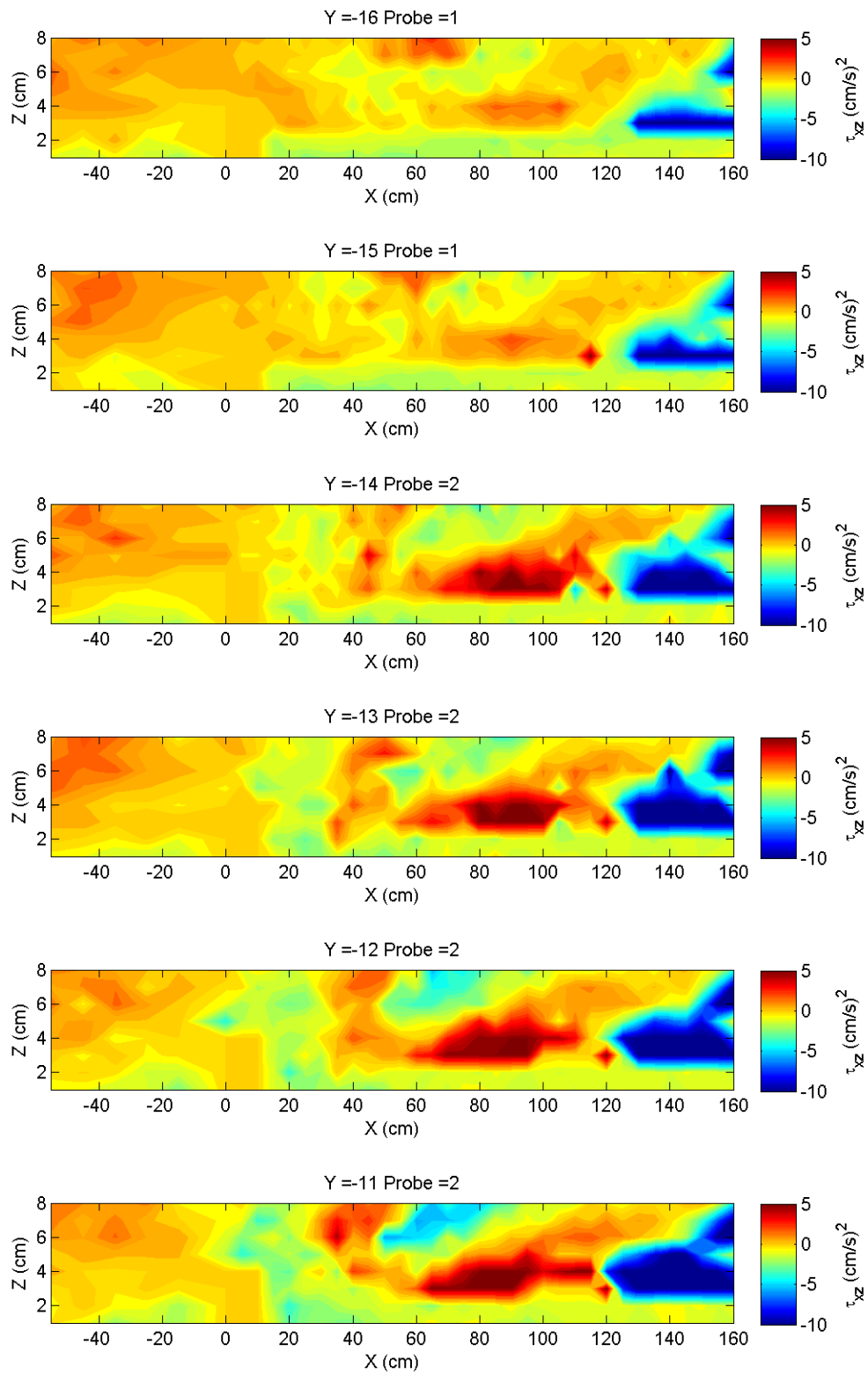
## 15. Reynolds Shear Stresses $\tau_{xz}$ in x and z-Directions

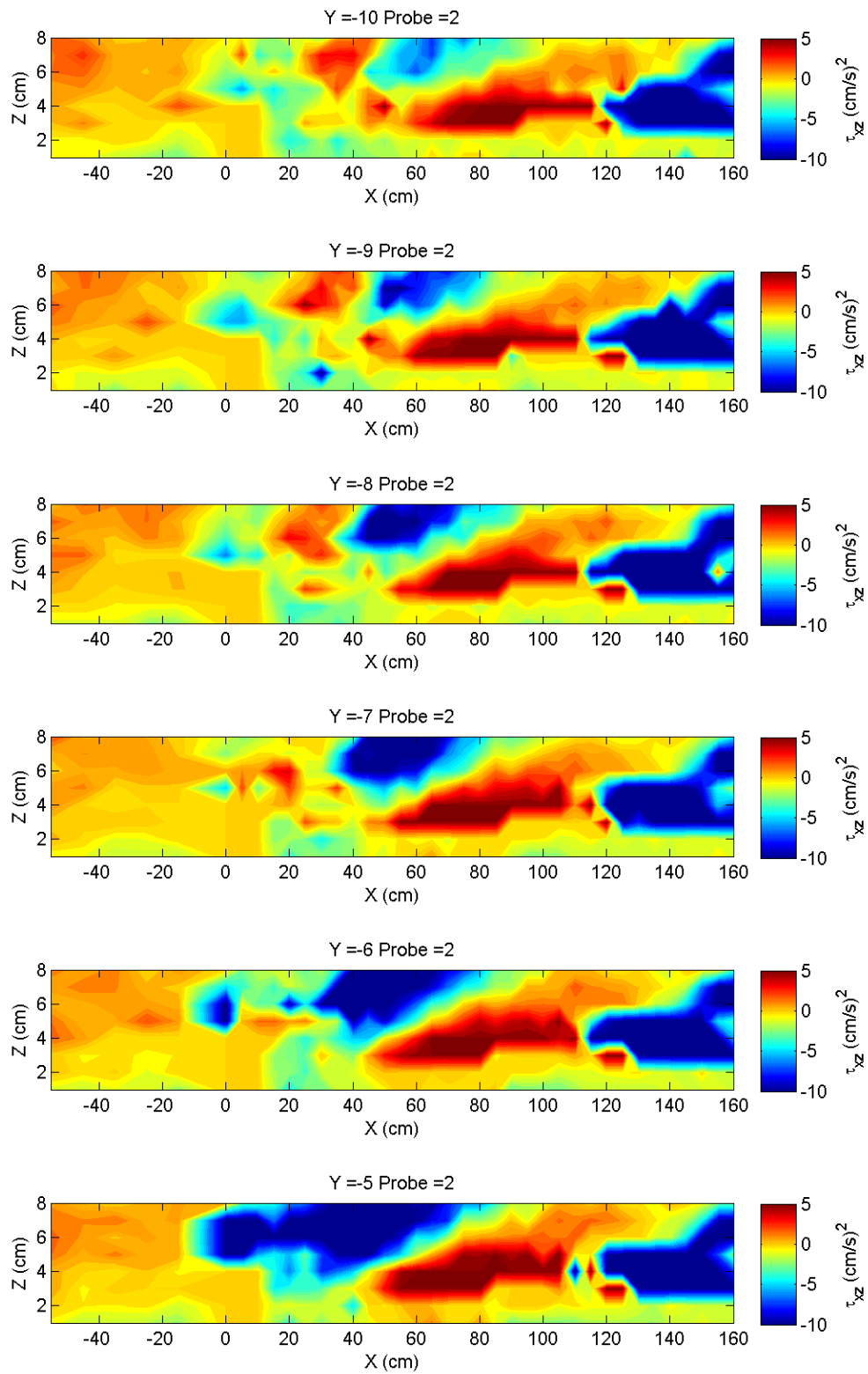


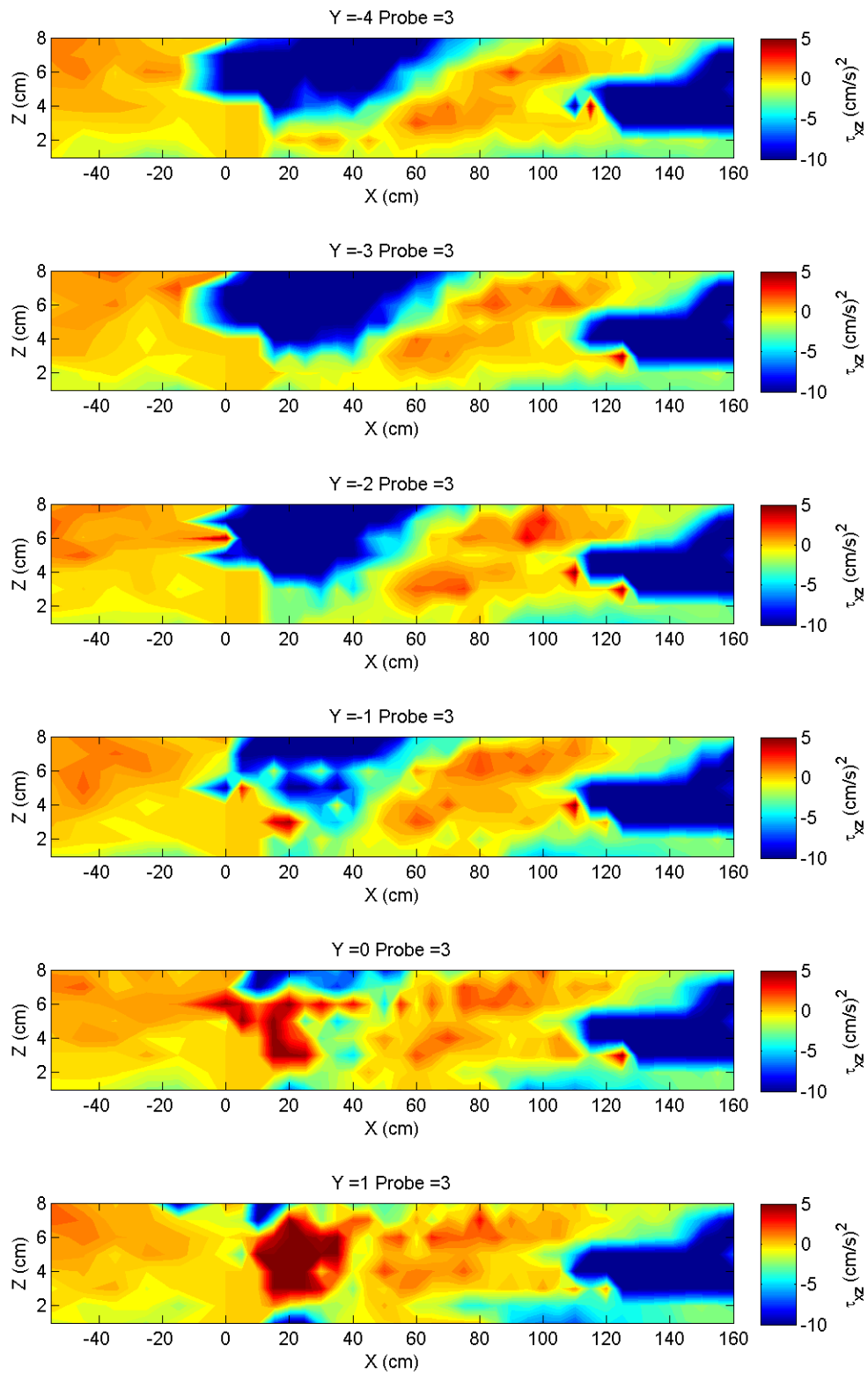


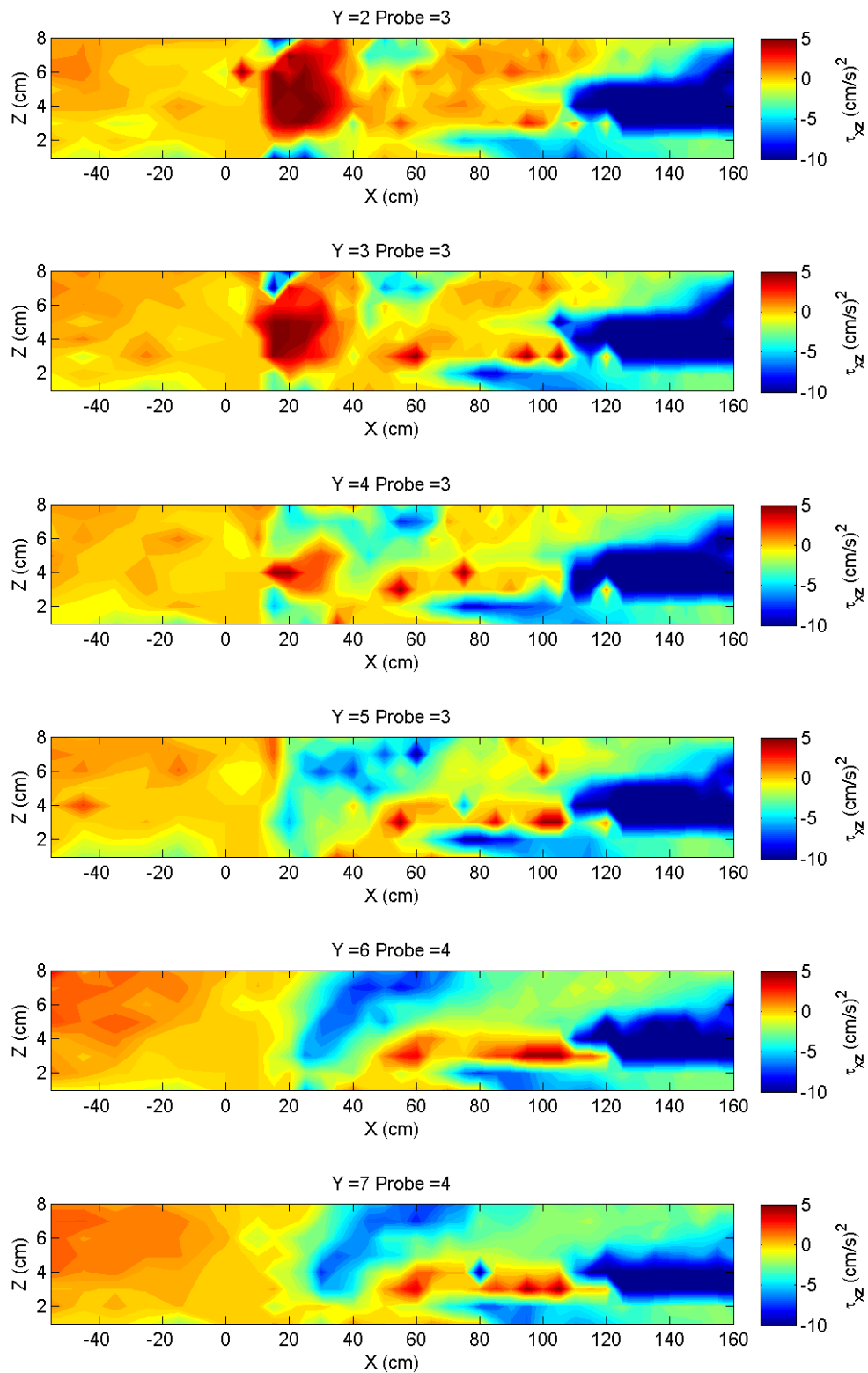


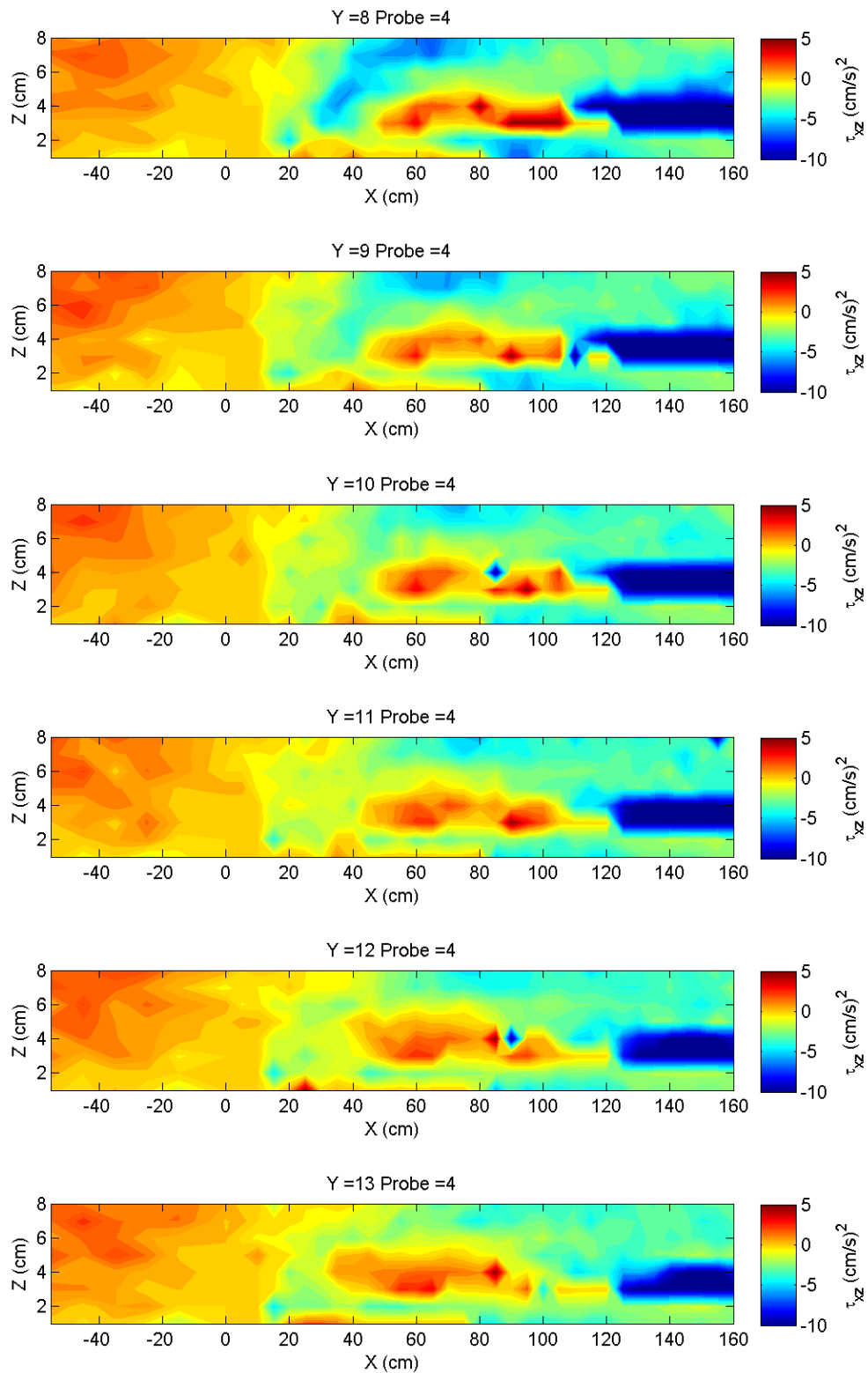


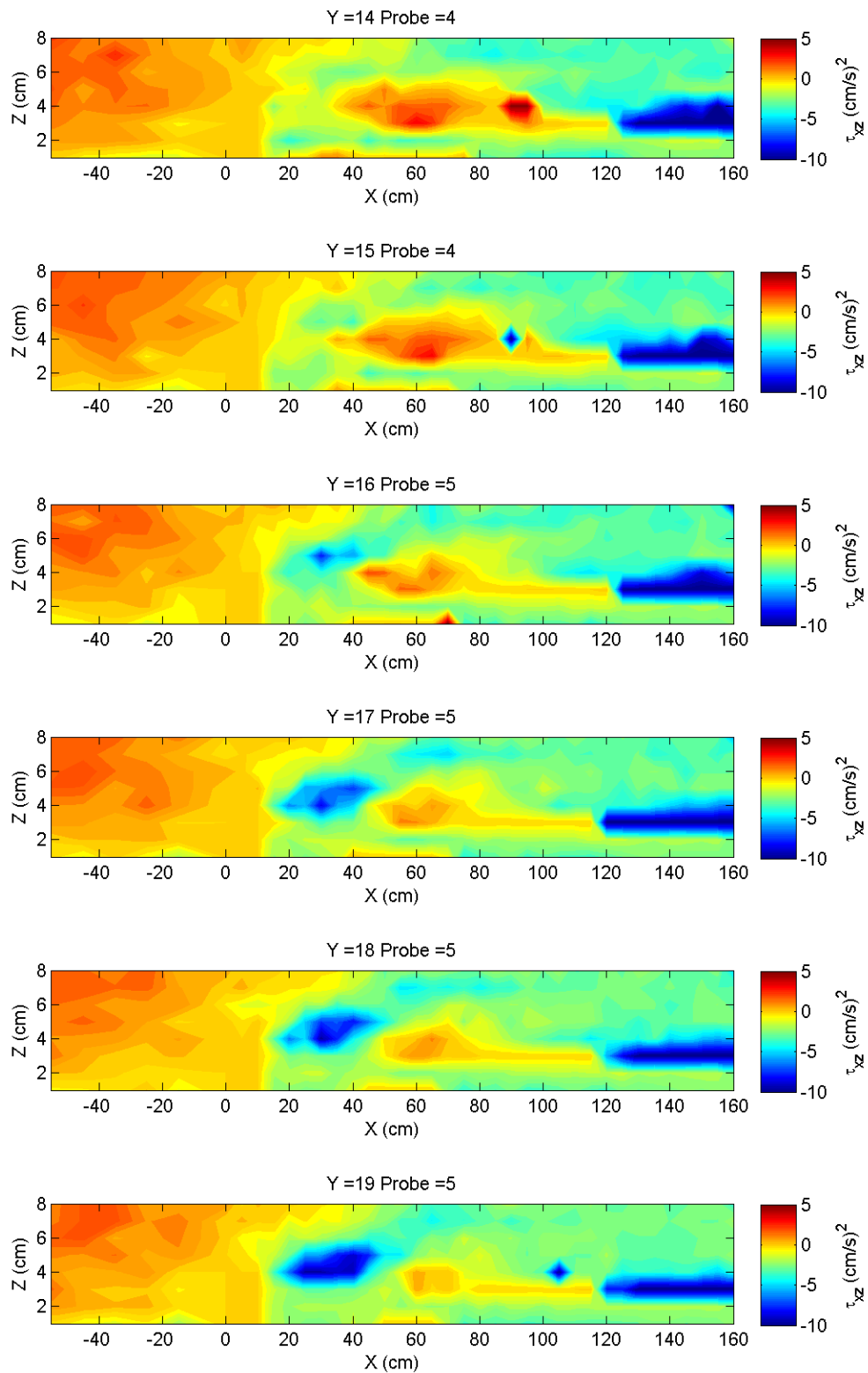




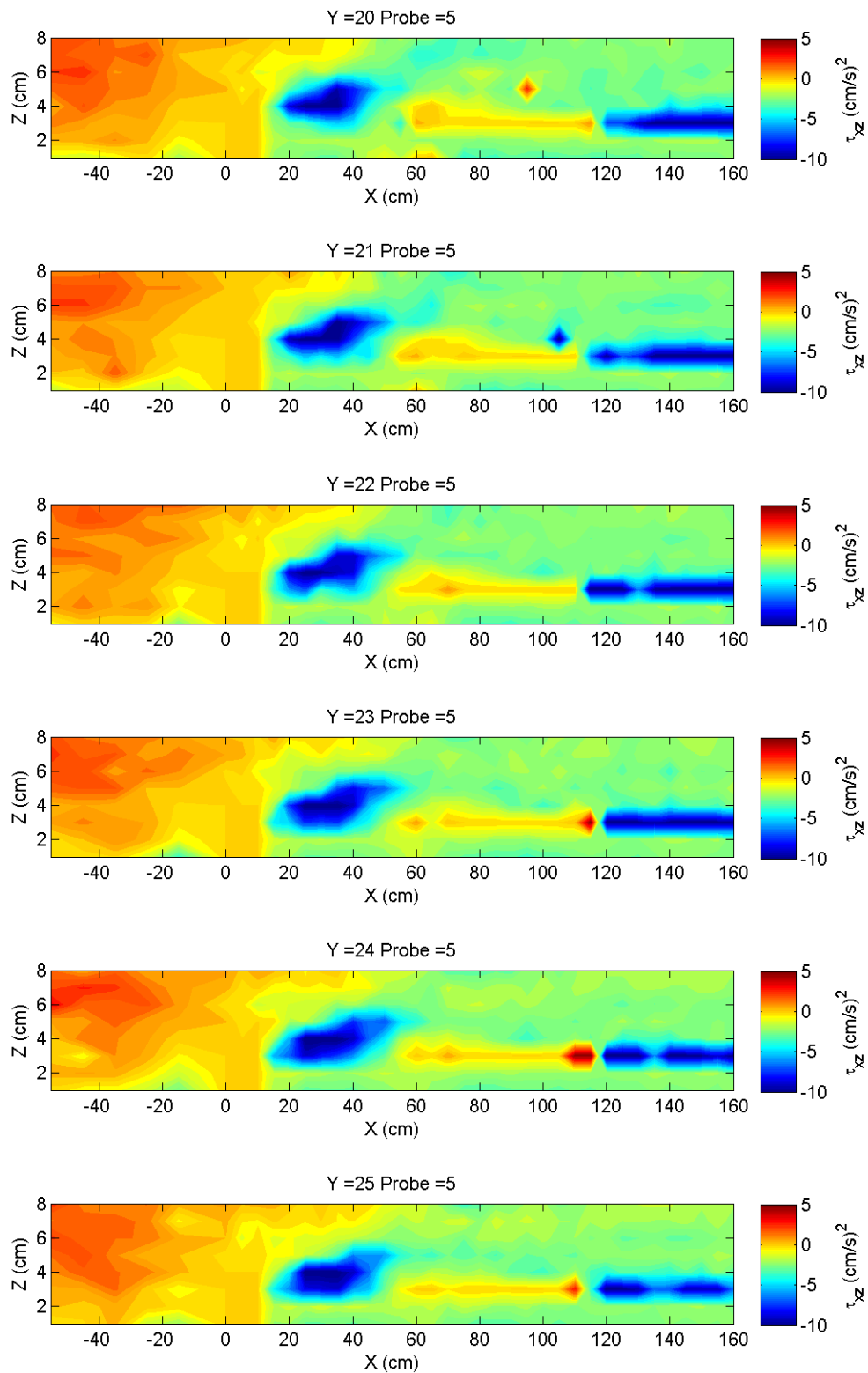


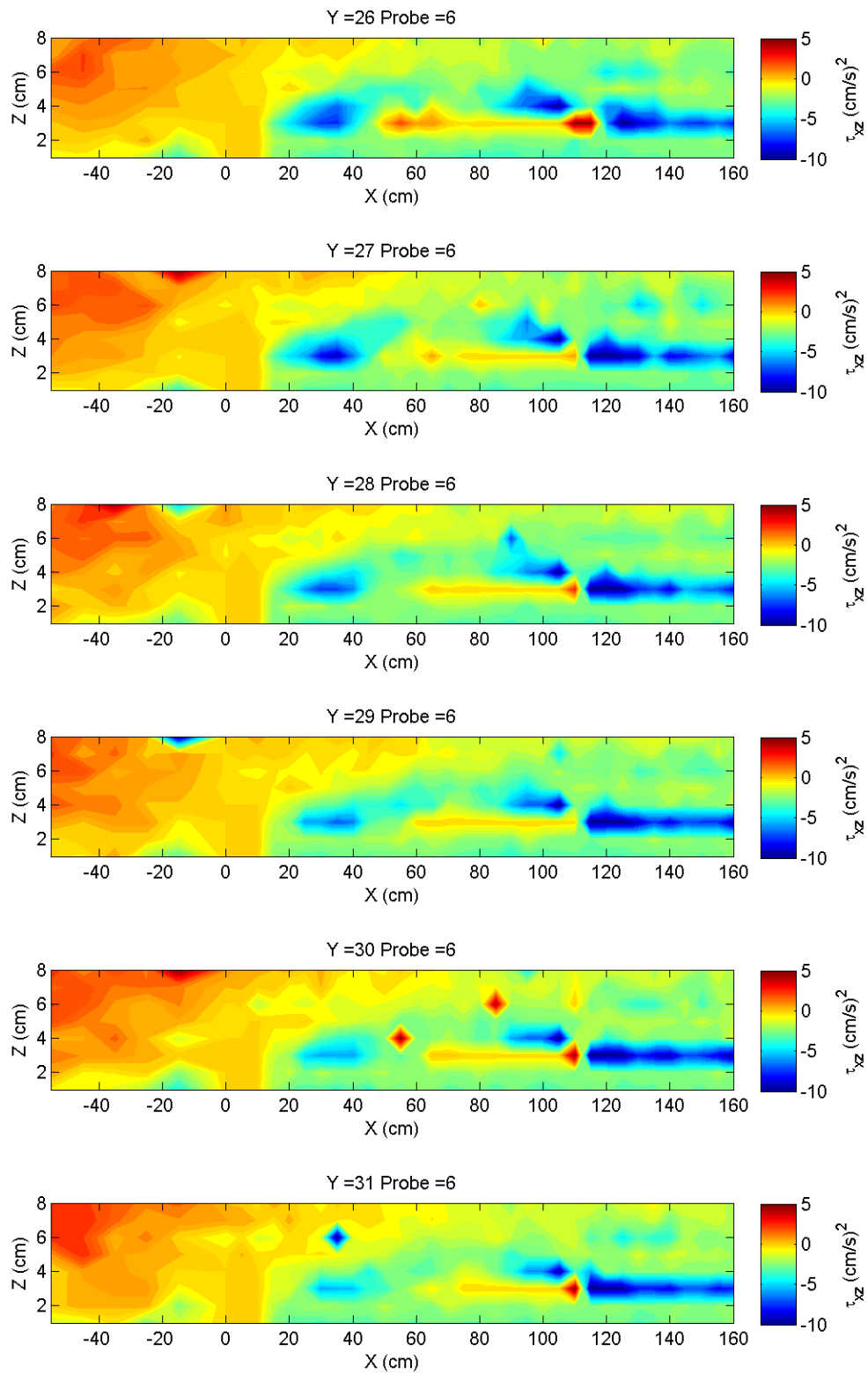


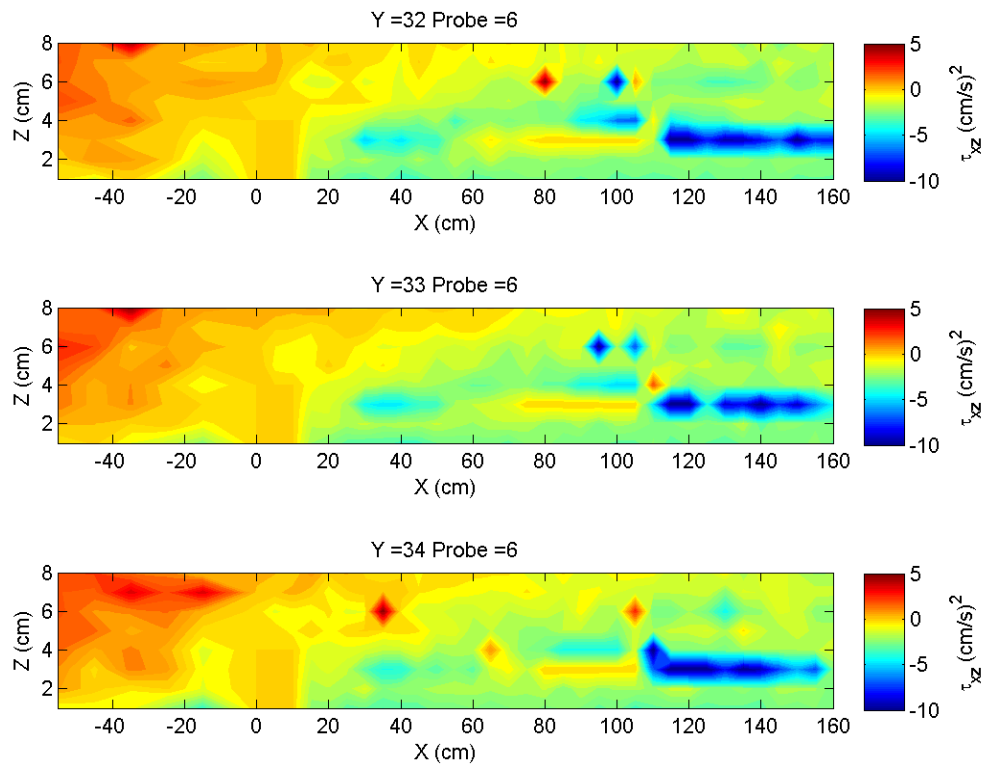




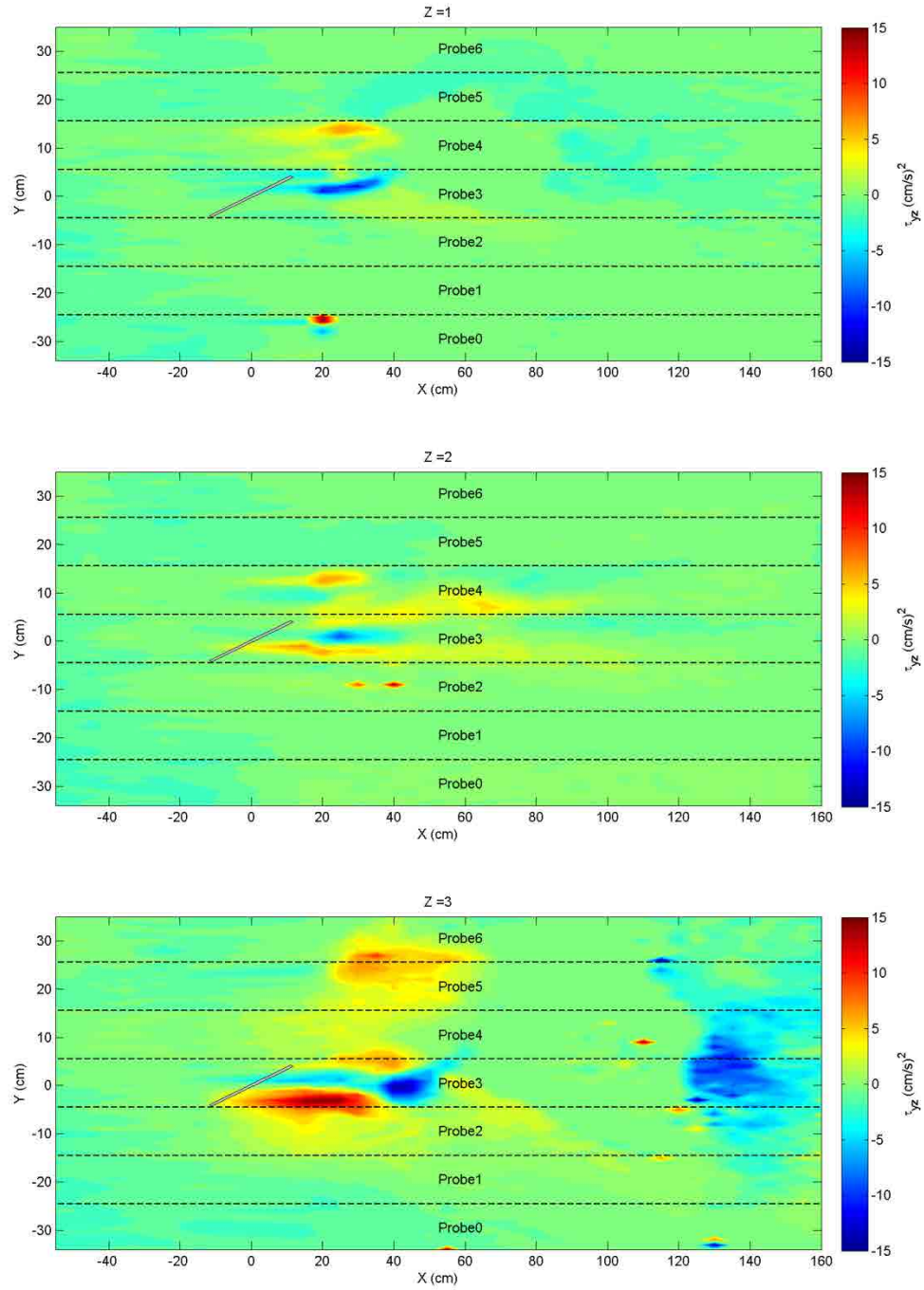


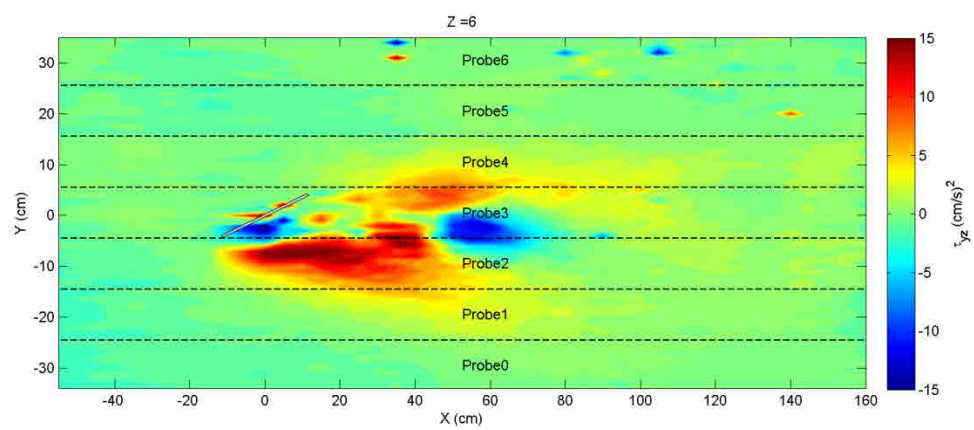
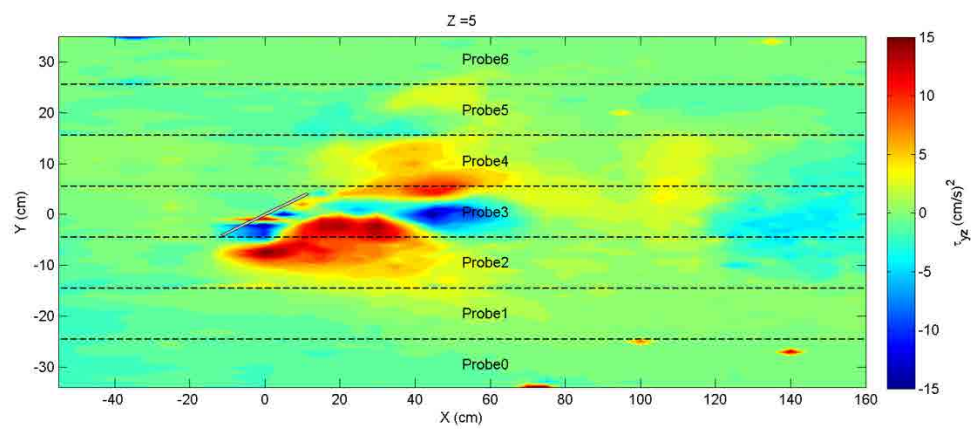
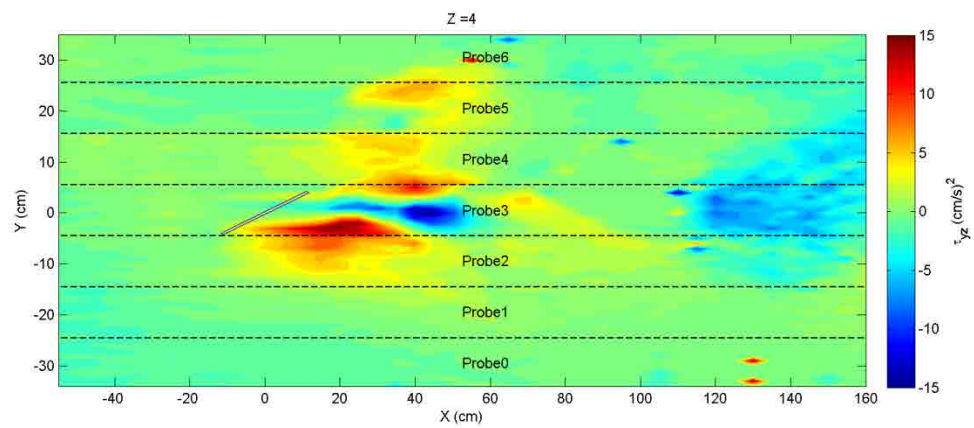


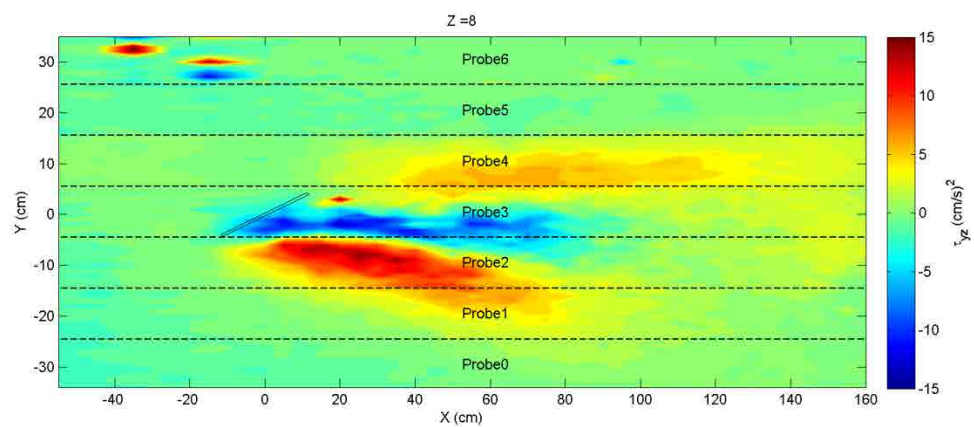
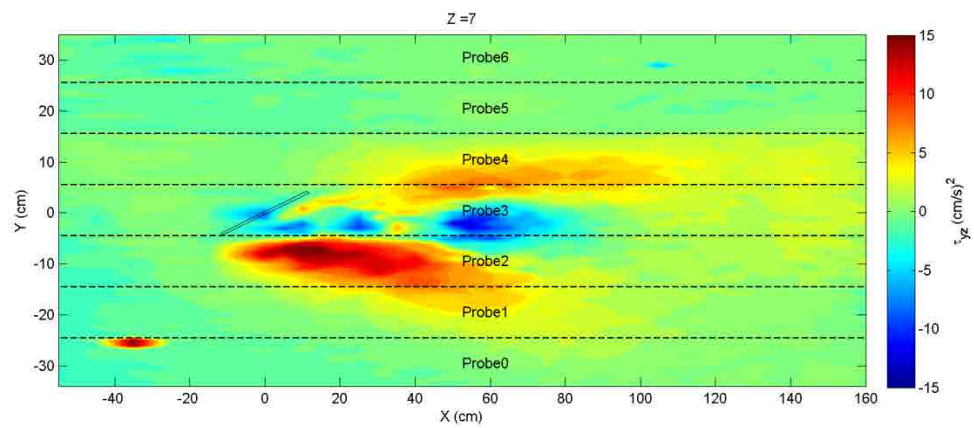




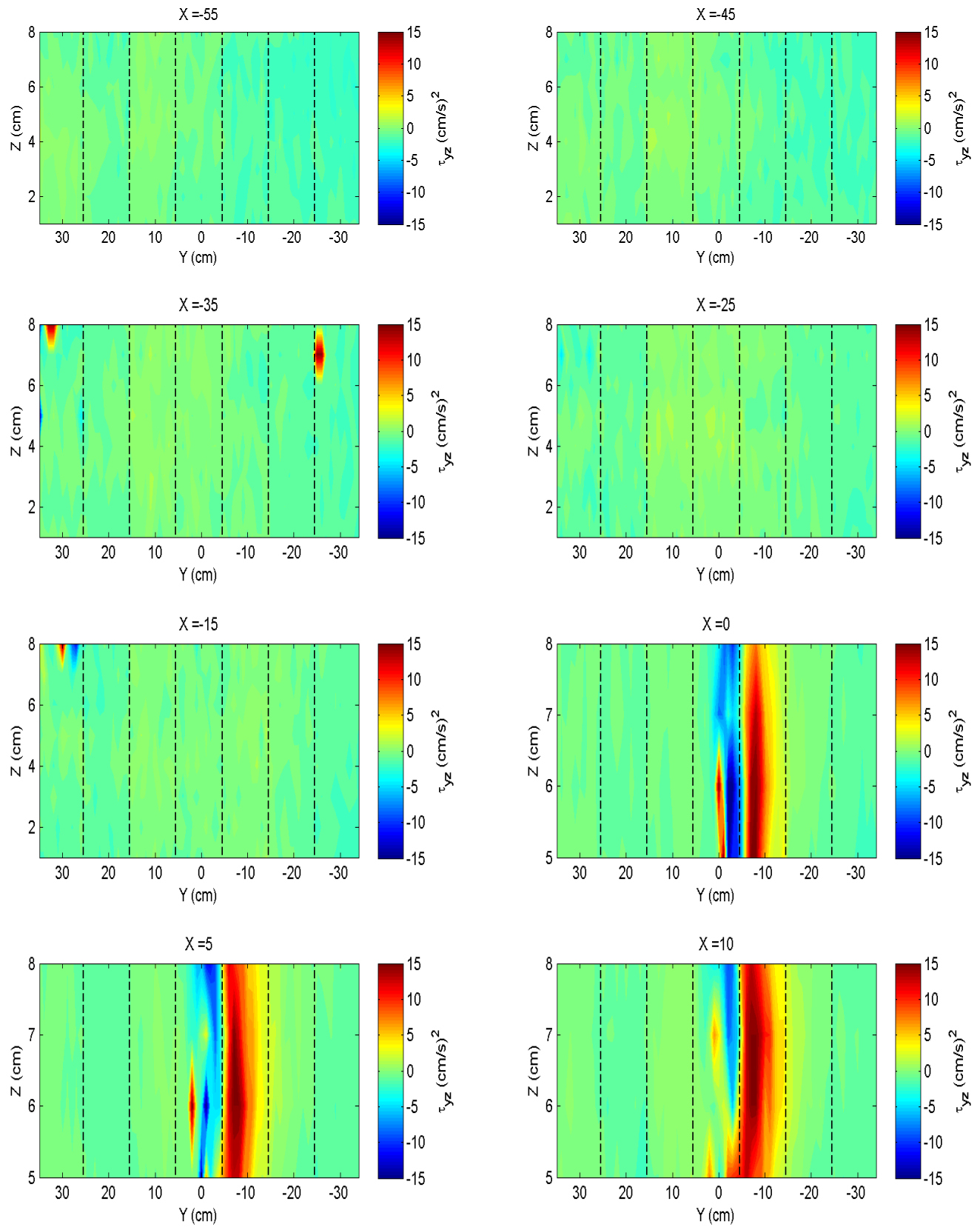
## 16. Reynolds Shear Stresses $\tau_{yz}$ in x and y-Directions



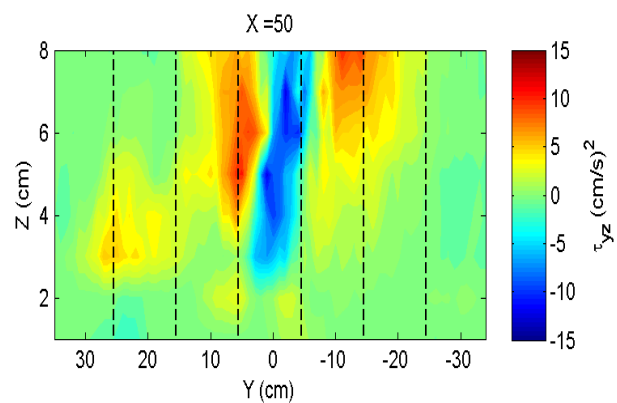
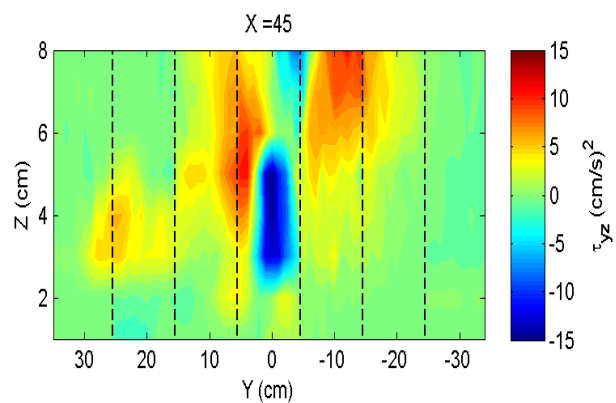
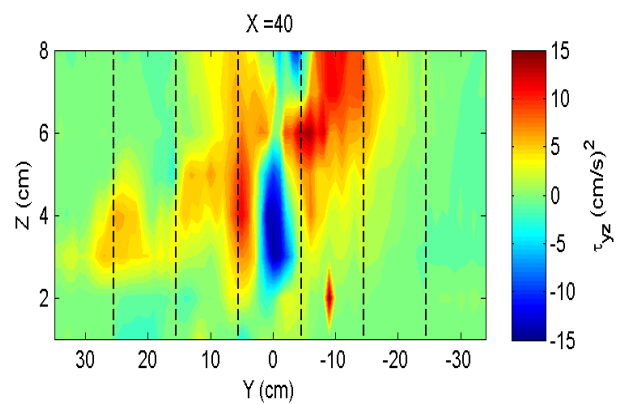
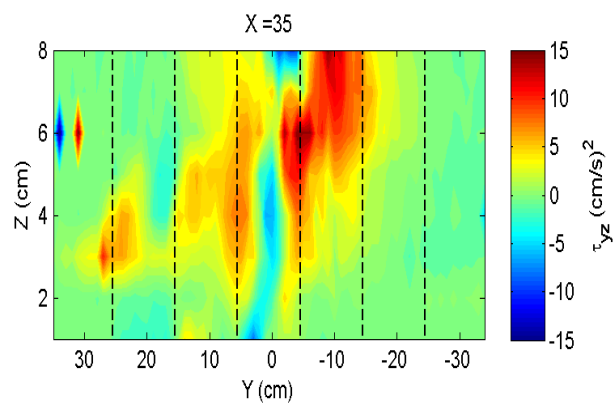
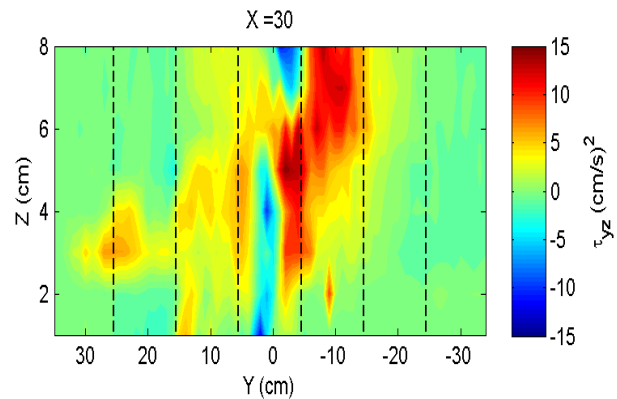
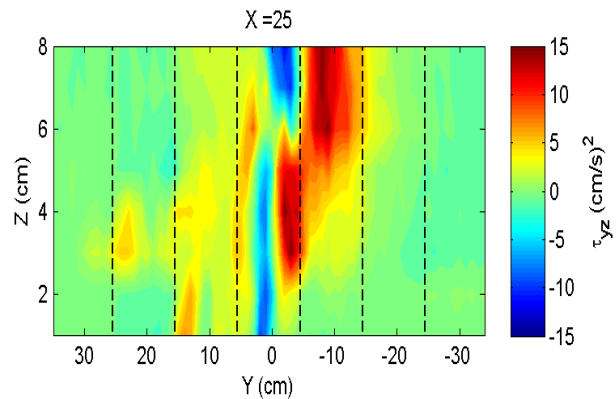
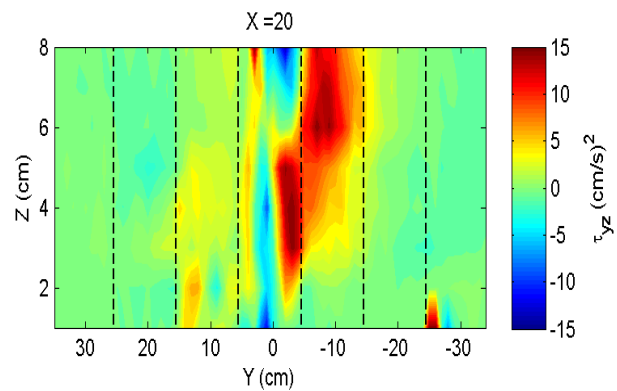
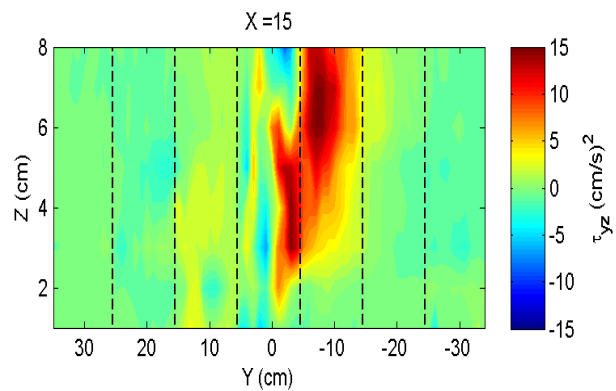




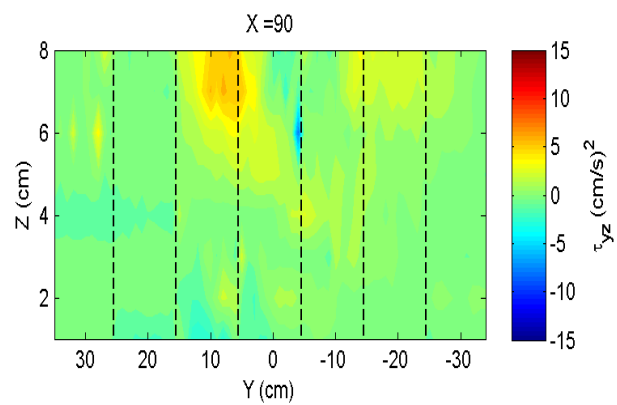
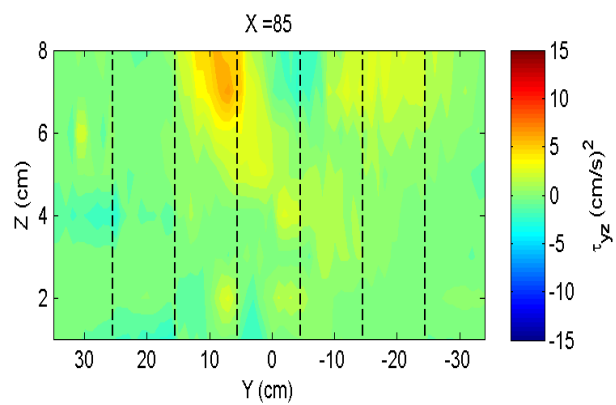
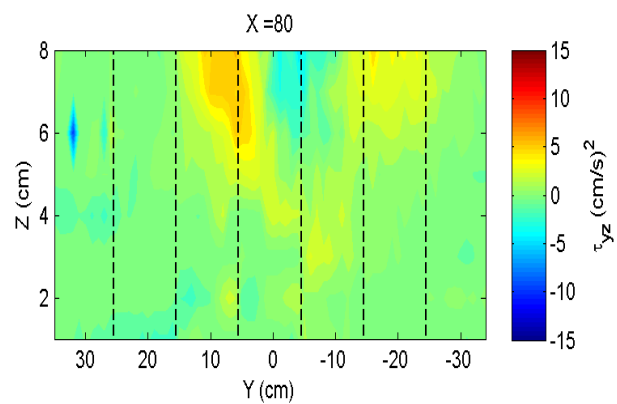
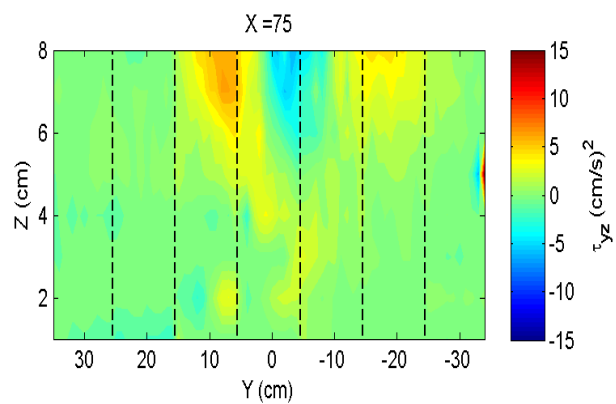
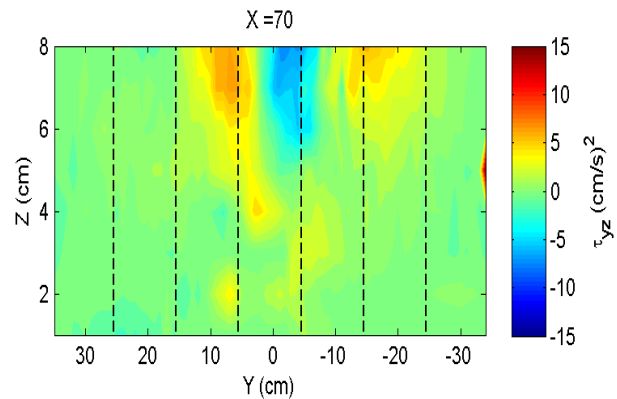
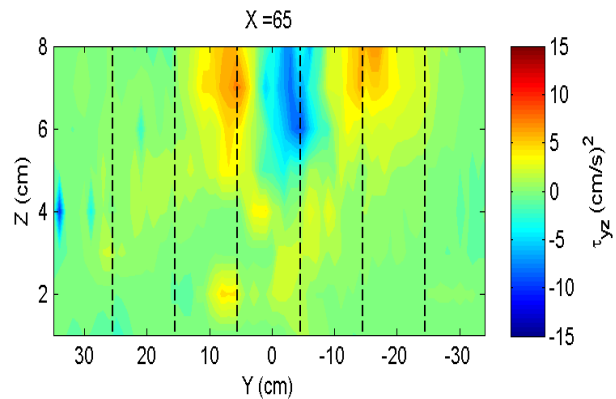
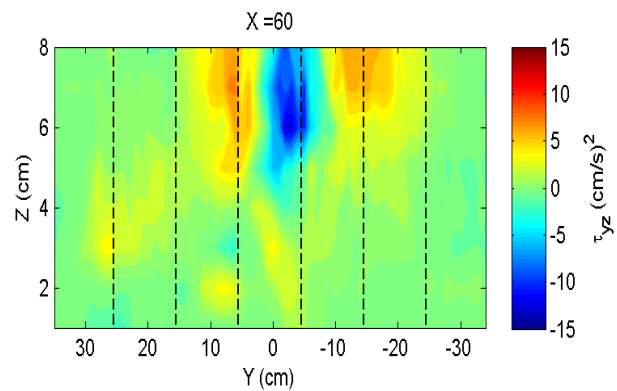
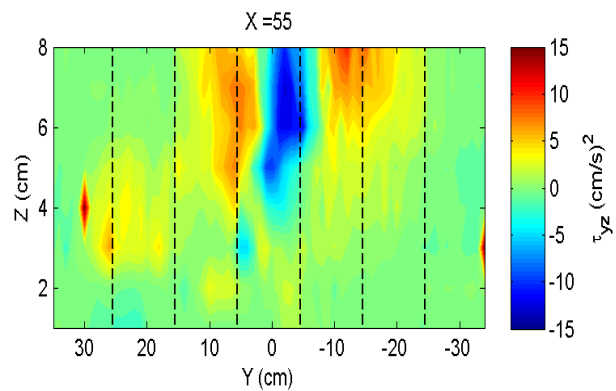
## 17. Reynolds Shear Stresses $\tau_{yz}$ in y and z-Directions

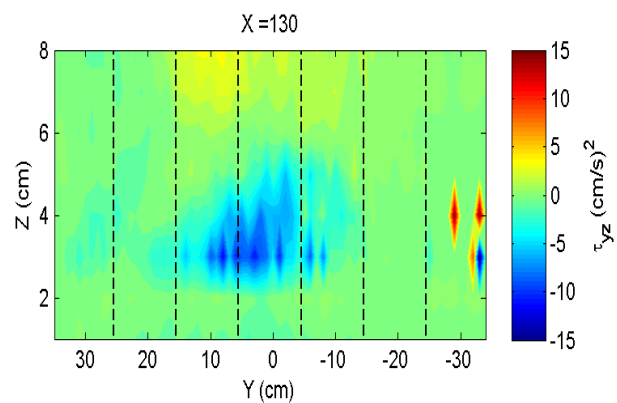
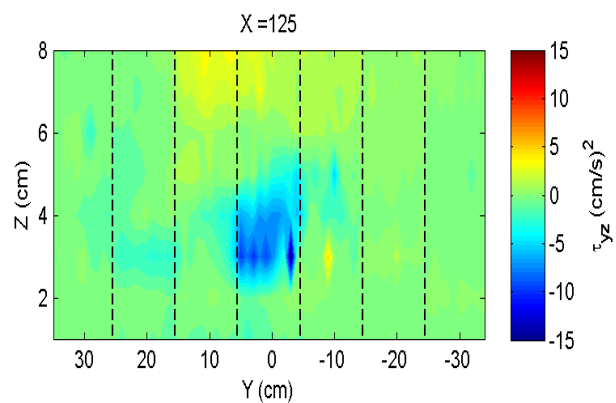
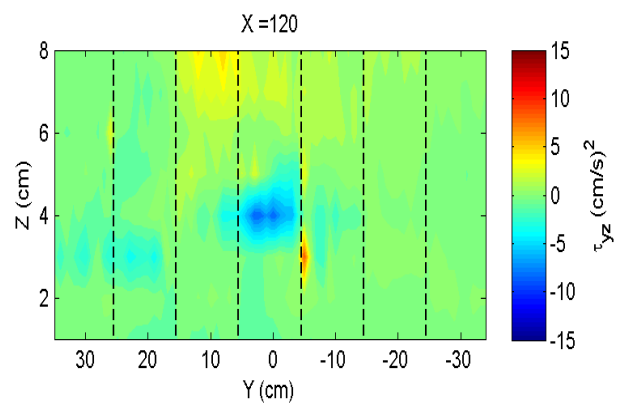
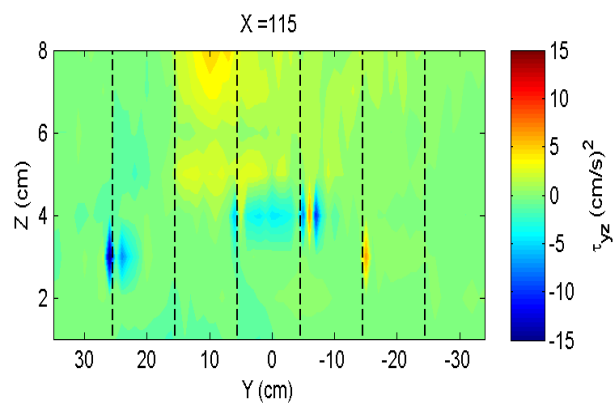
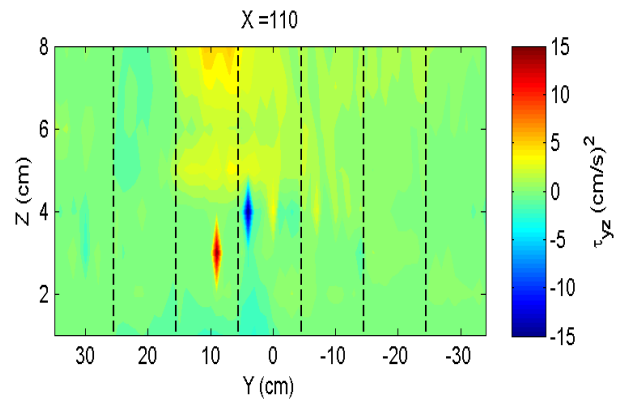
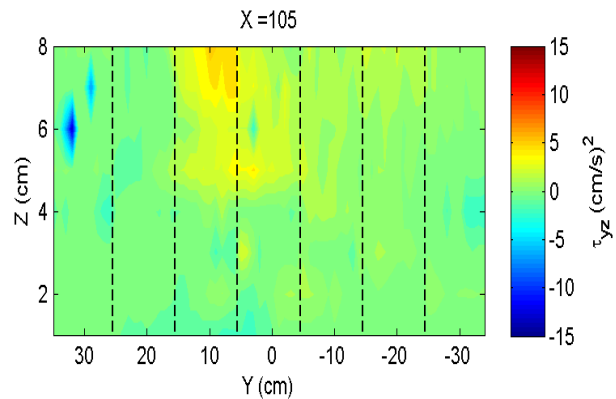
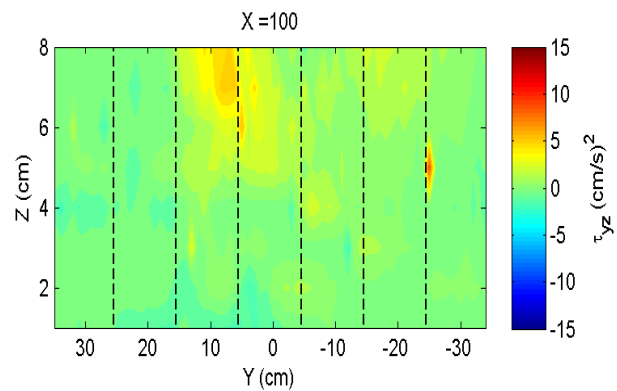
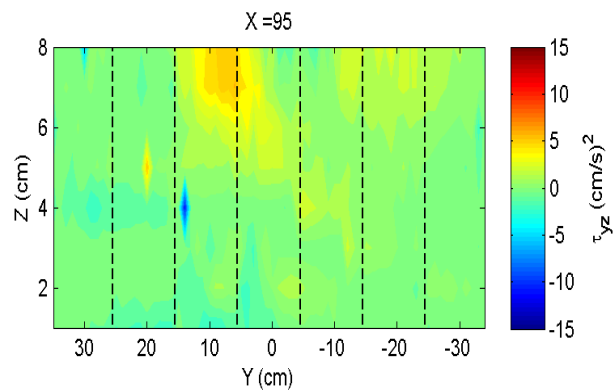


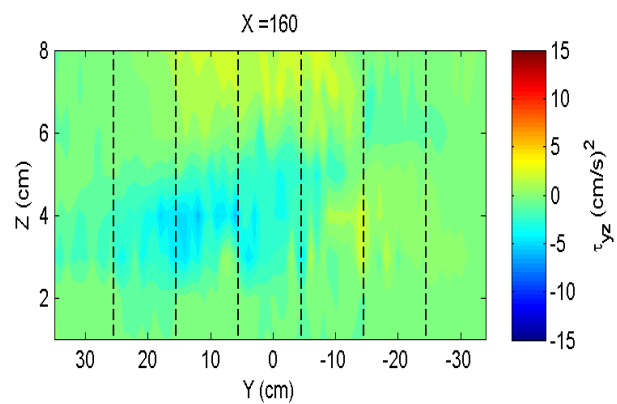
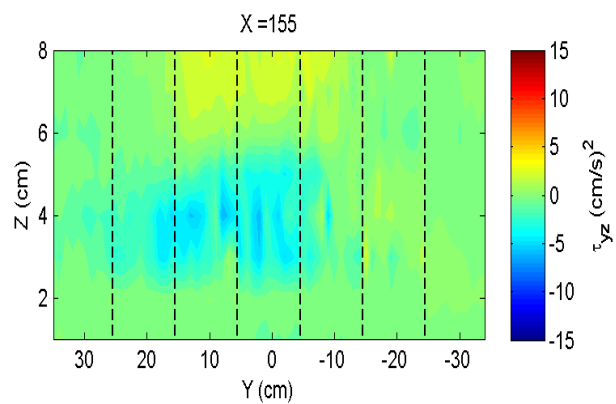
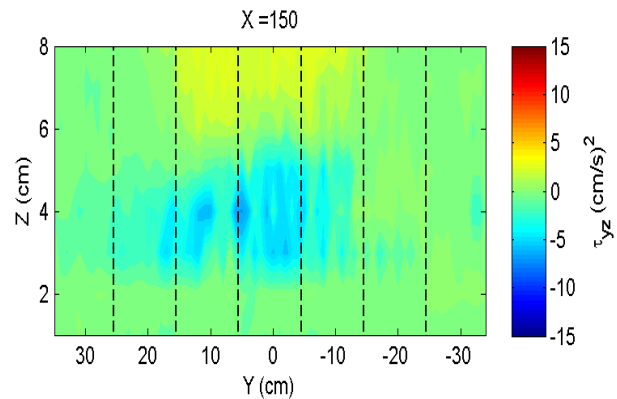
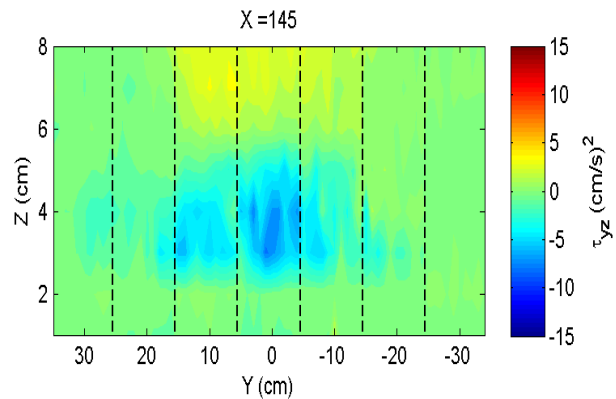
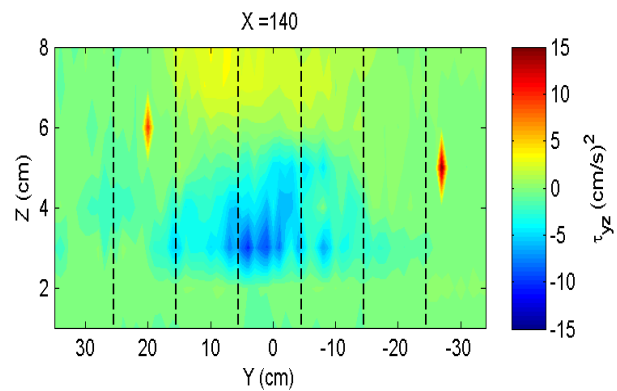
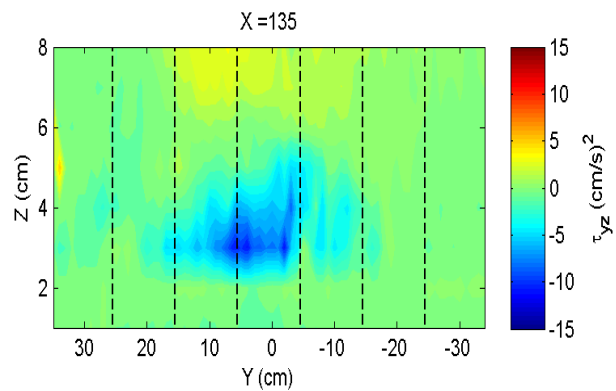




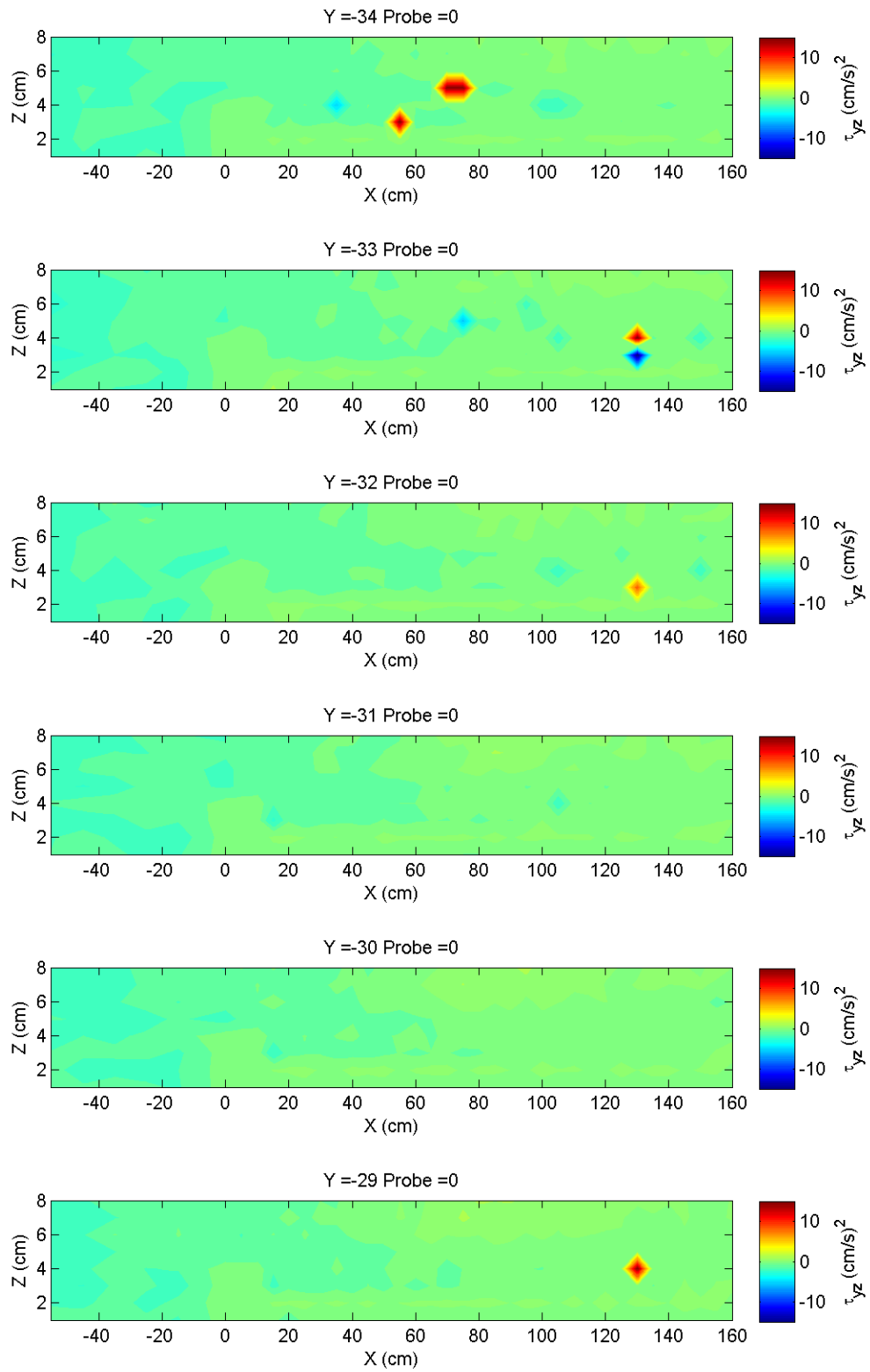


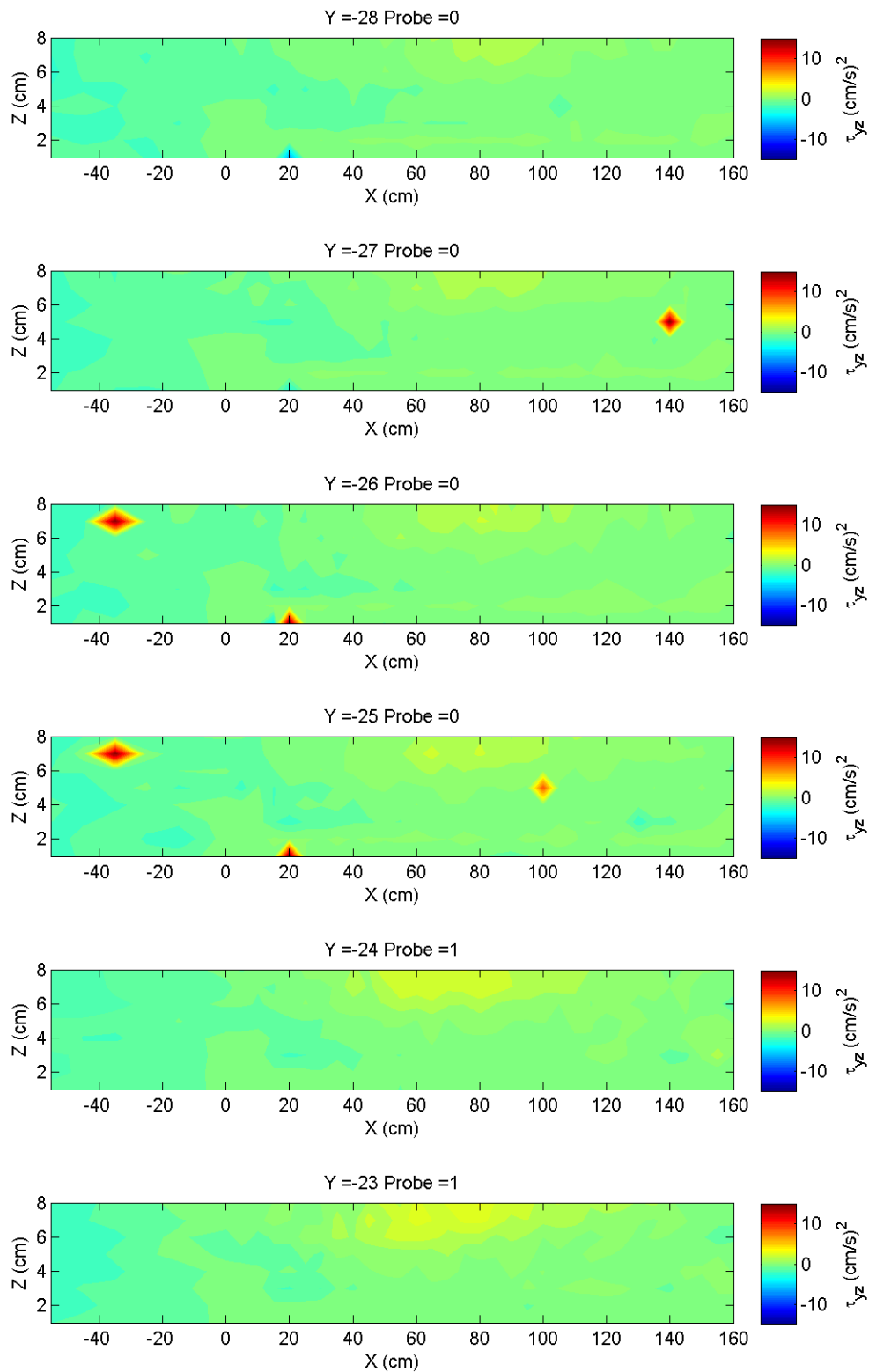


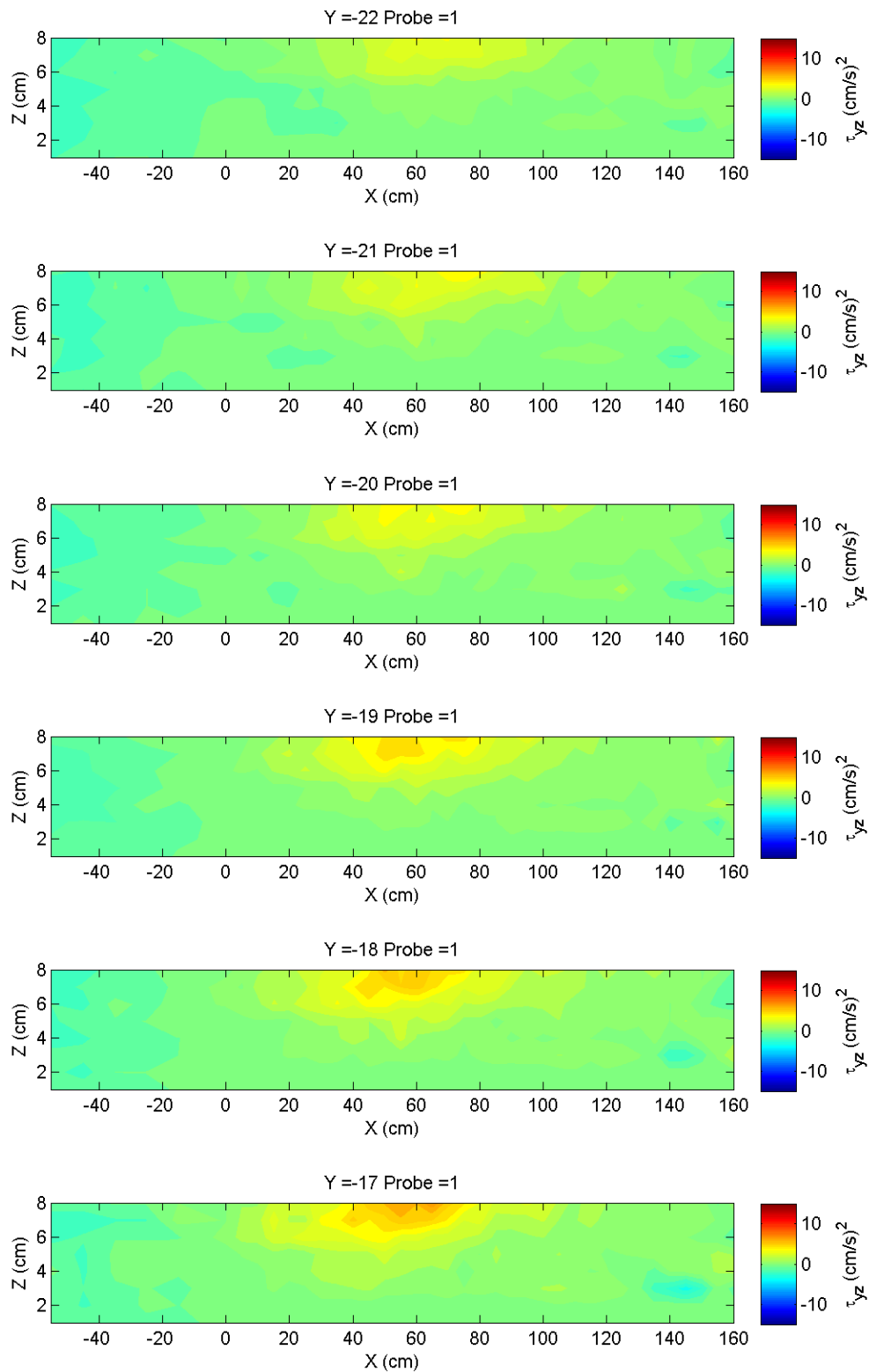


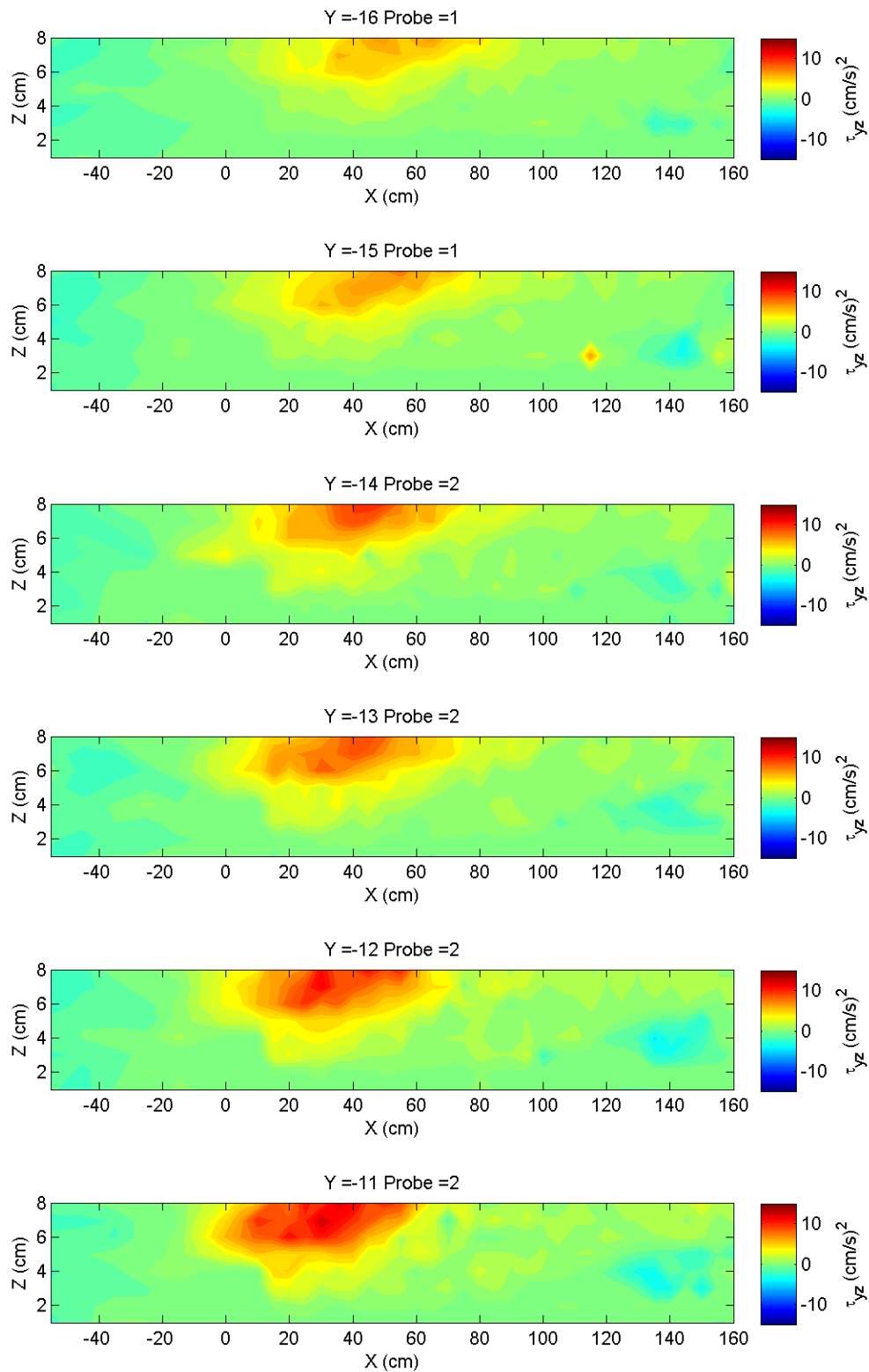


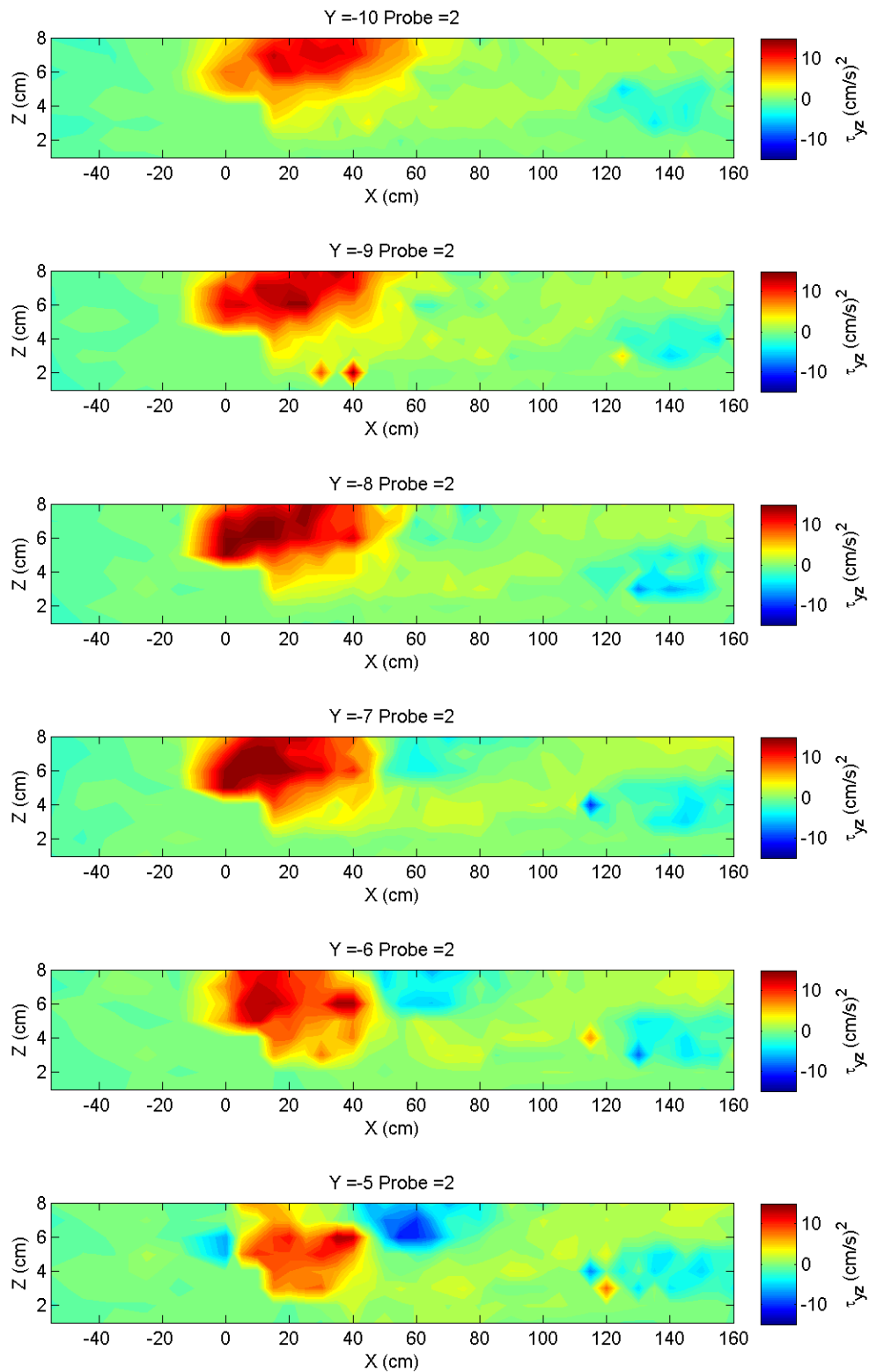
## 18. Reynolds Shear Stresses $\tau_{yz}$ in x and z-Directions



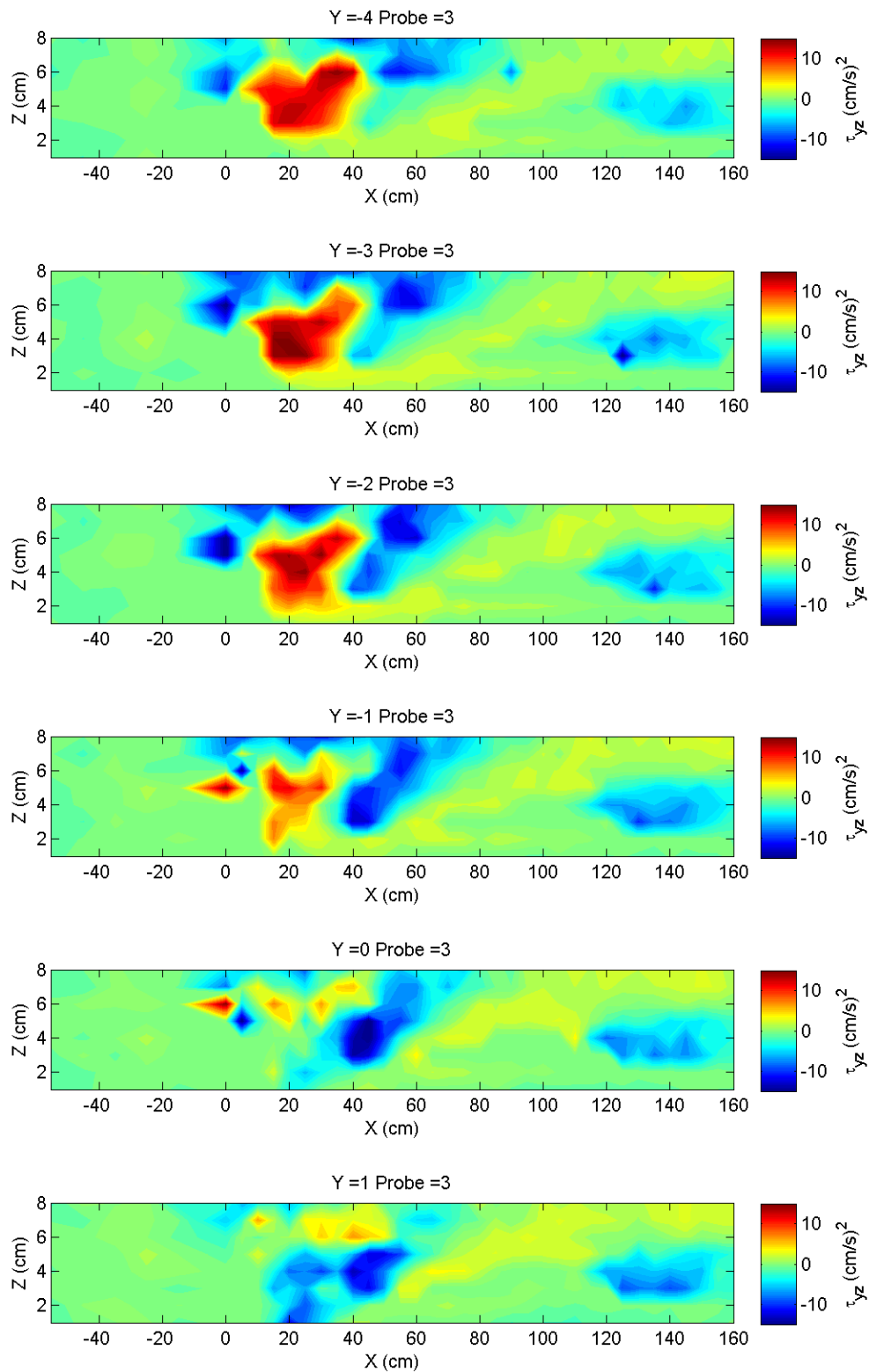


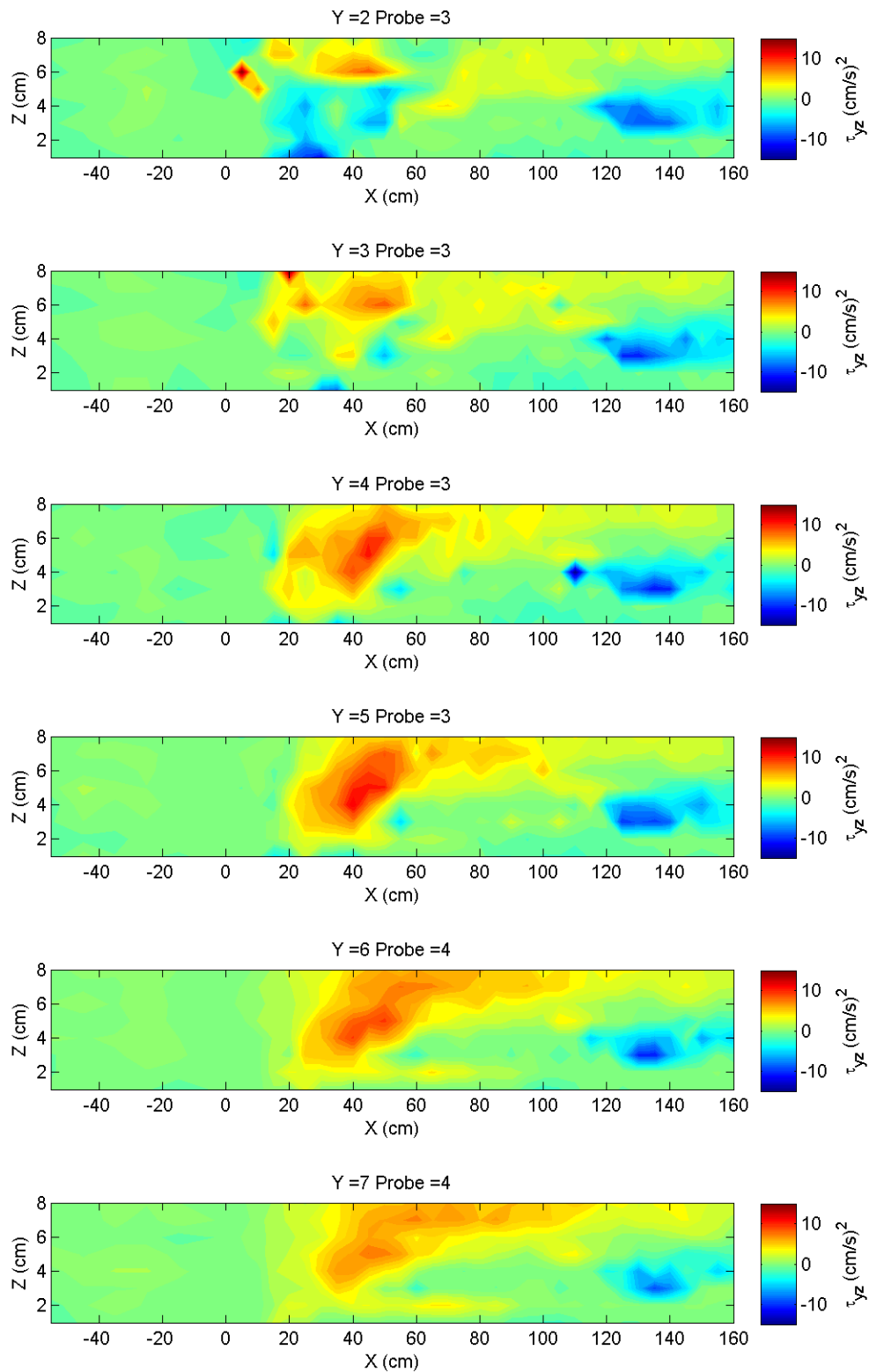


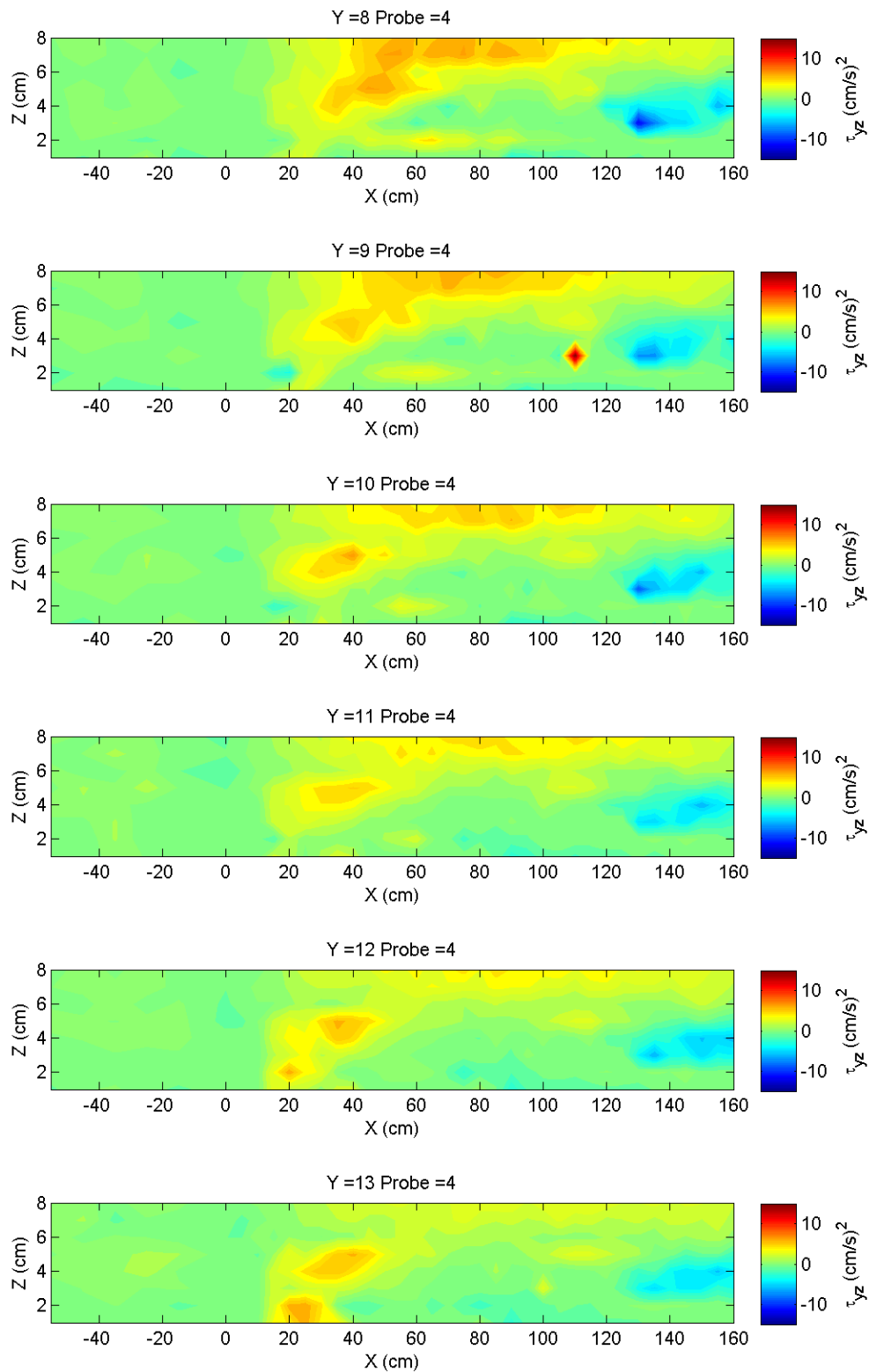


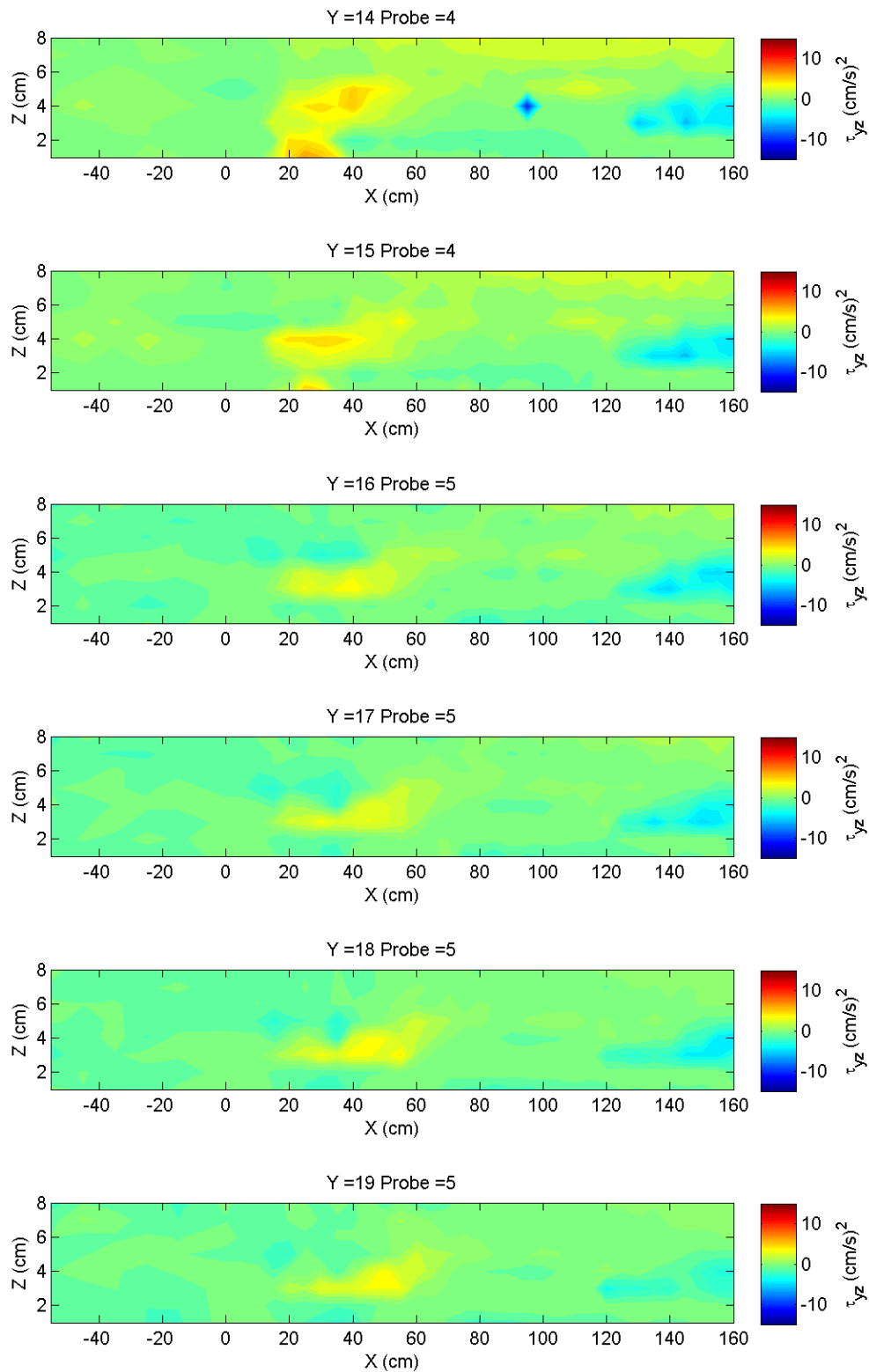


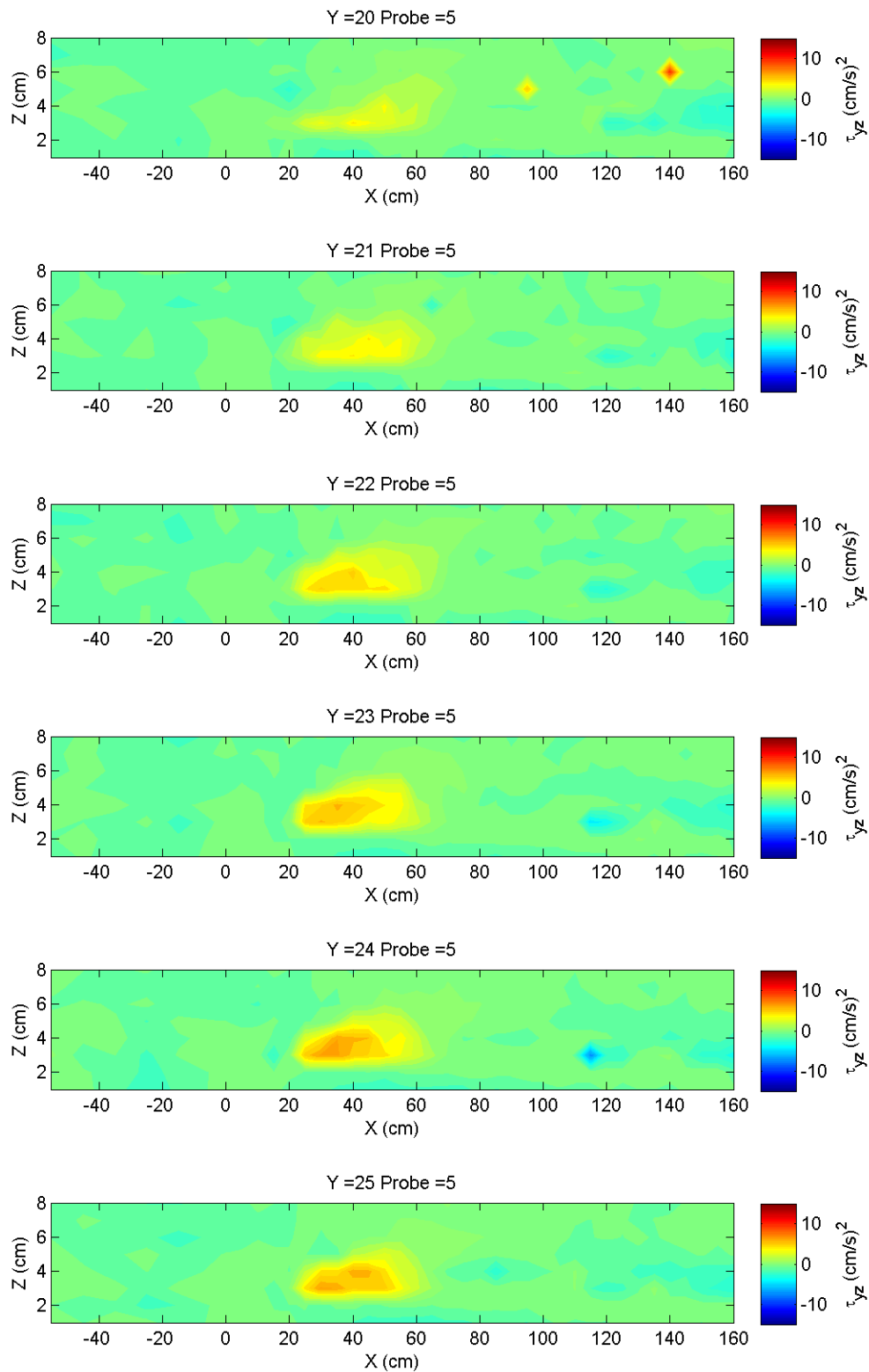


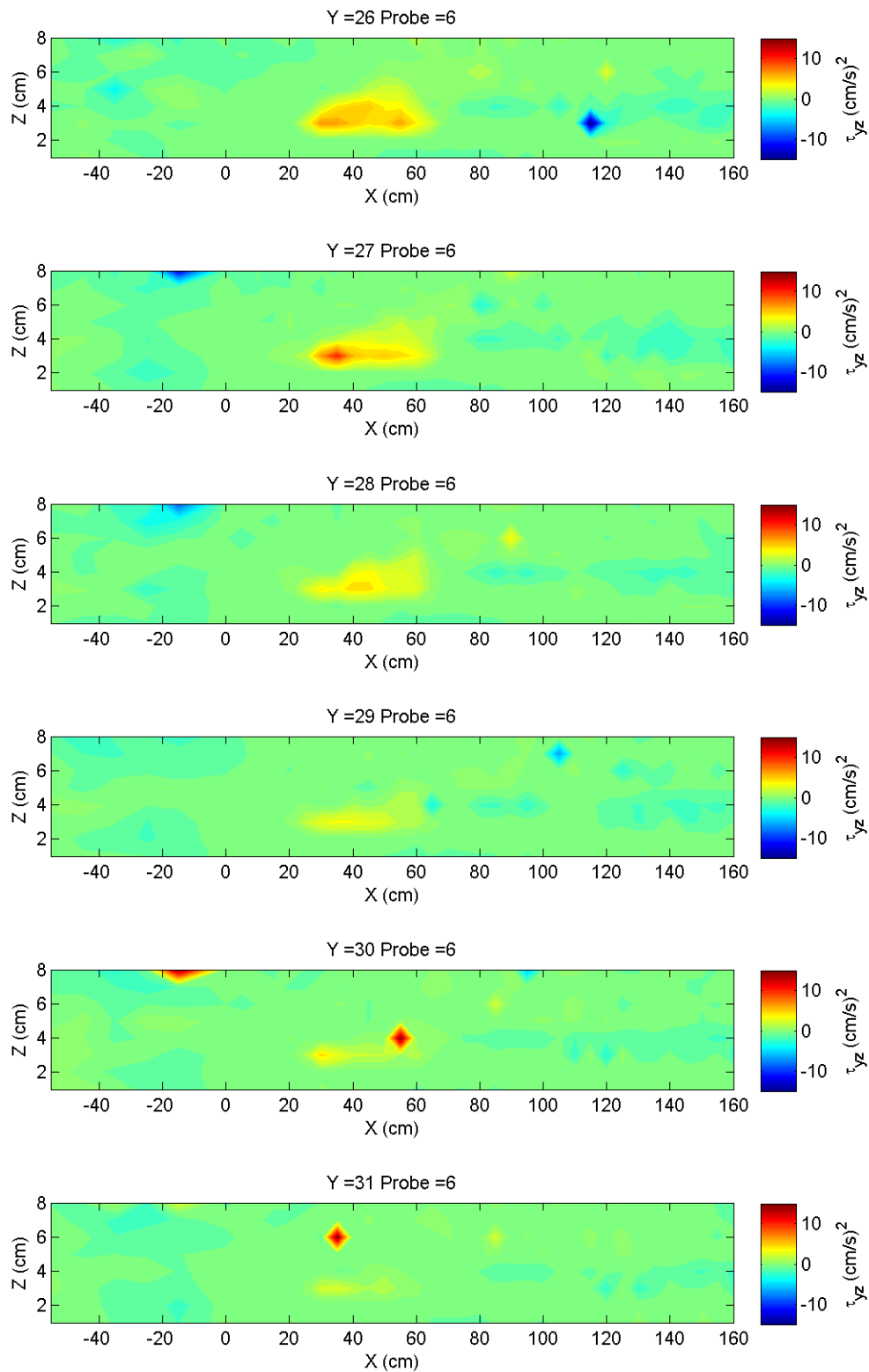


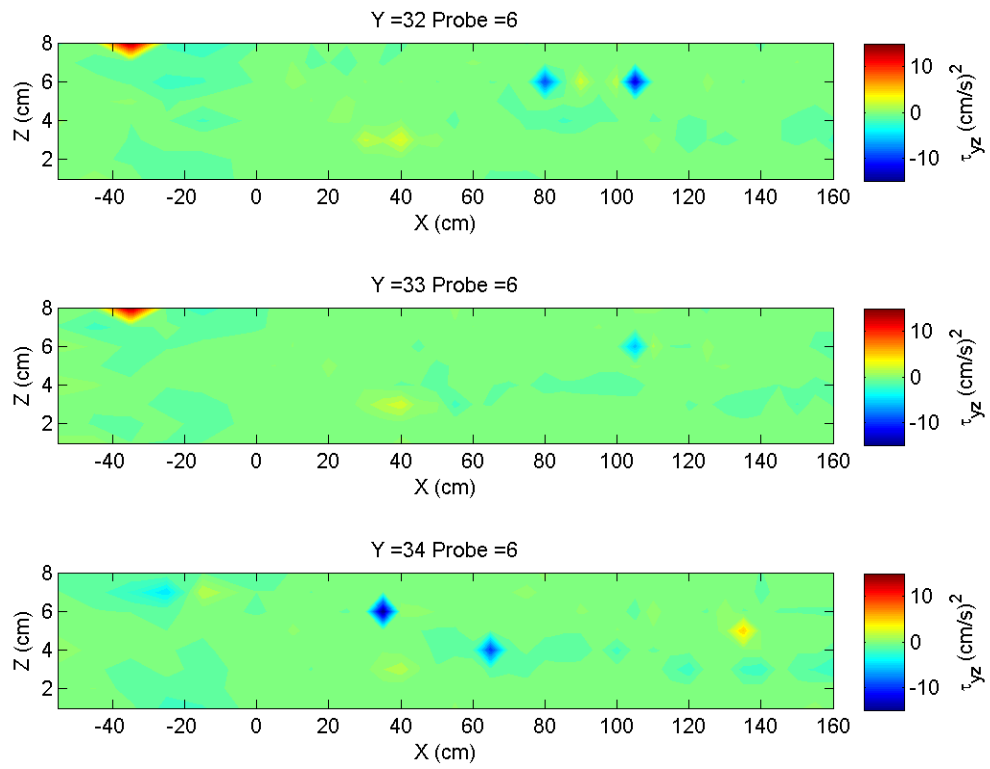










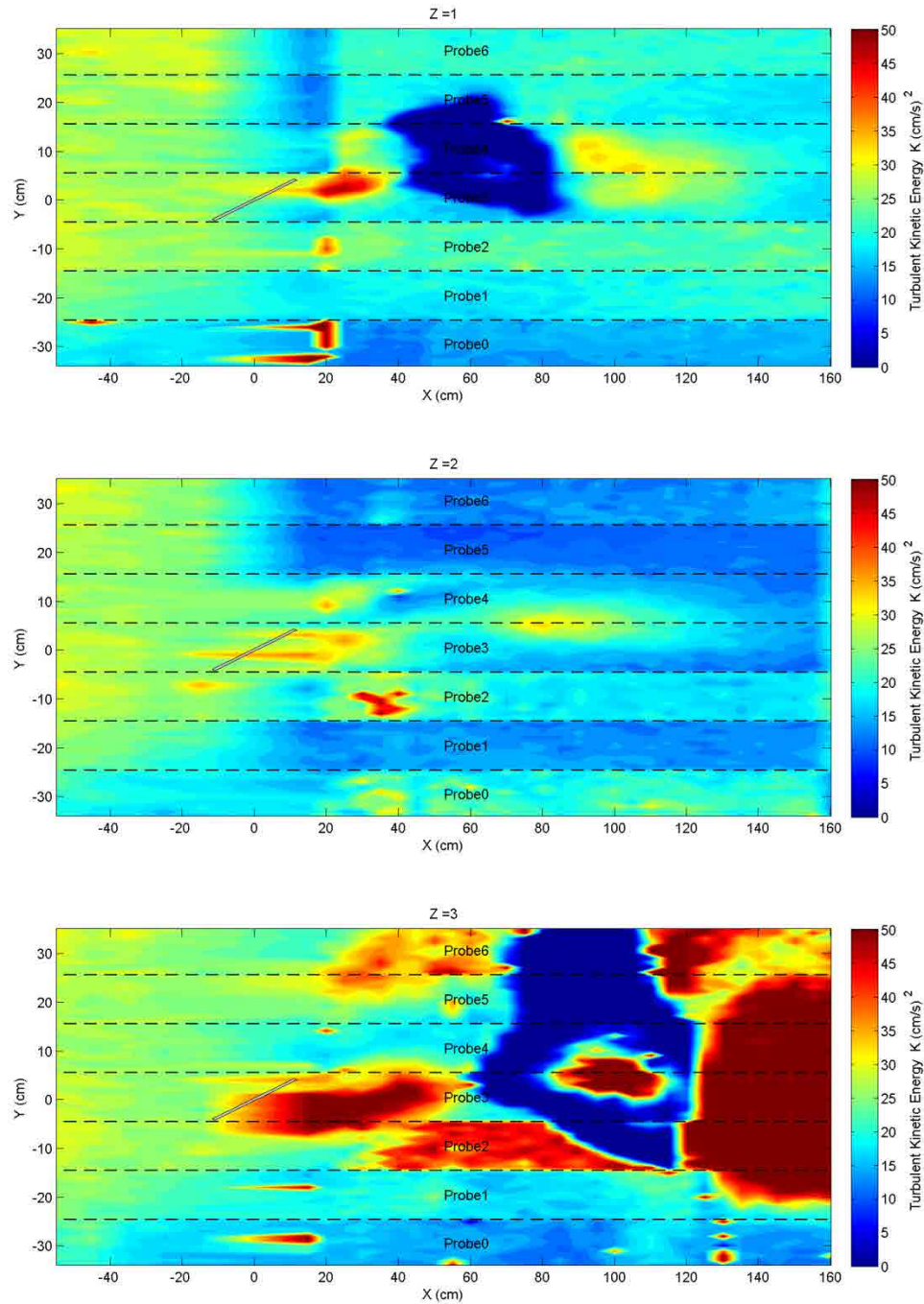


## Appendix C Results – Submerged Vanes Turbulence Statistics

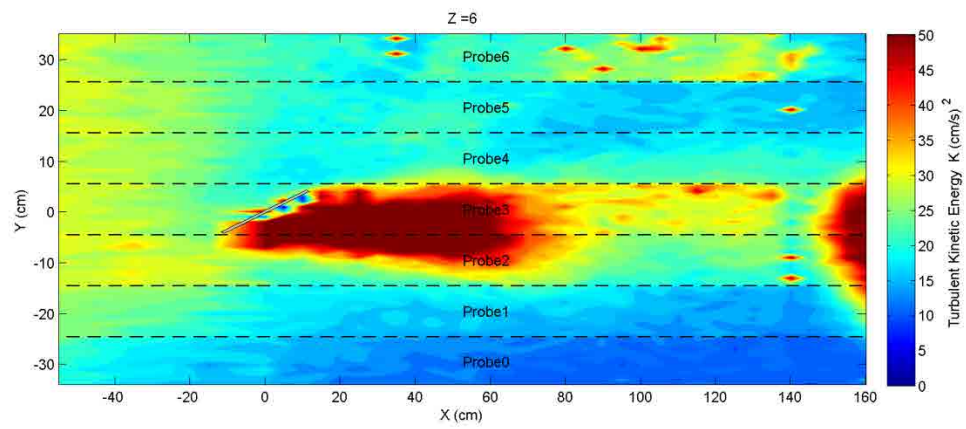
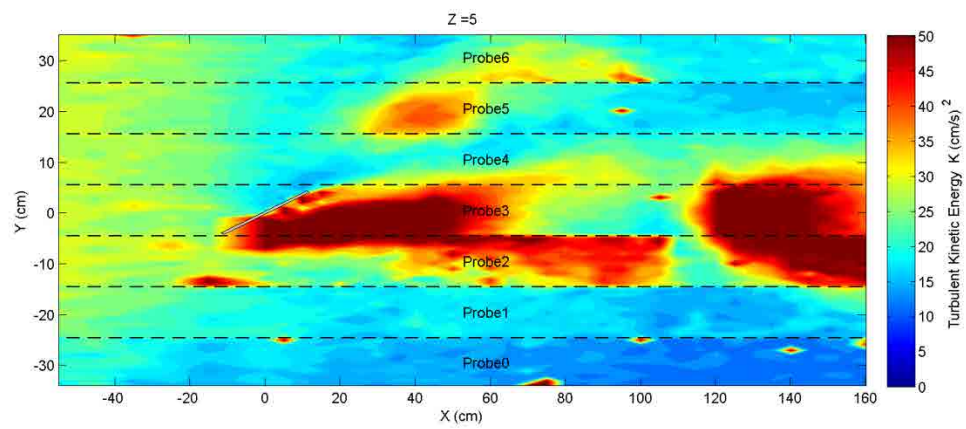
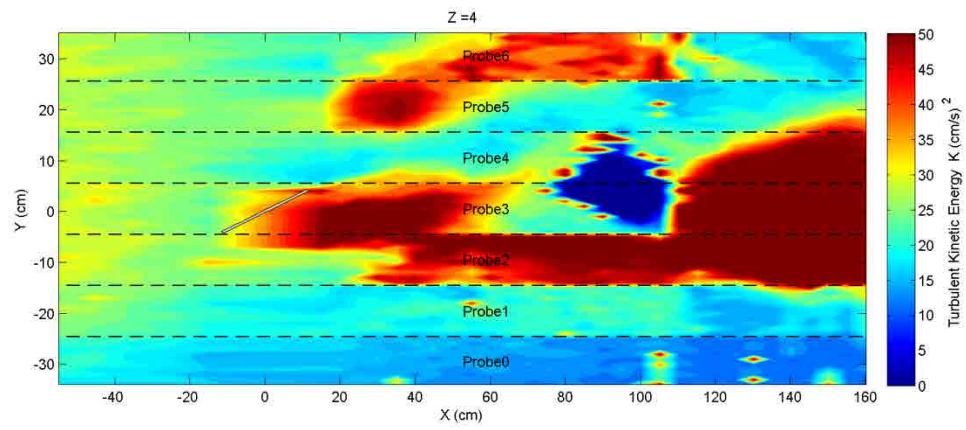
### C.3 Turbulent Kinetic Energy and Rate of Dissipation

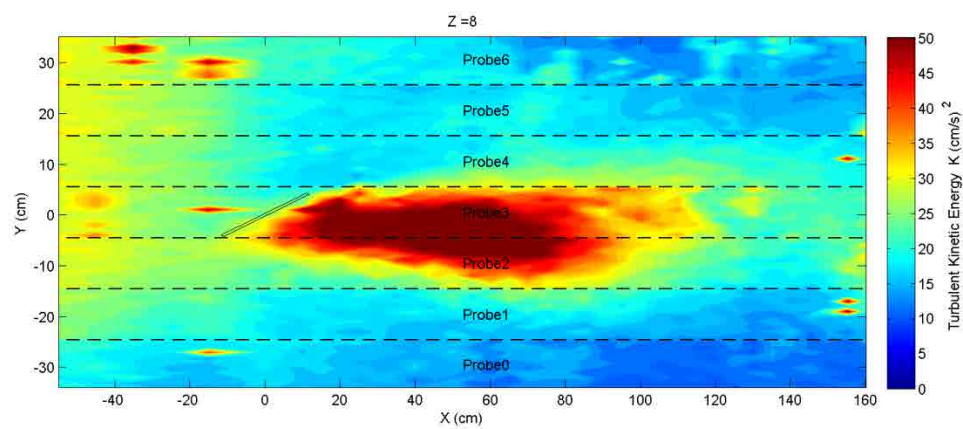
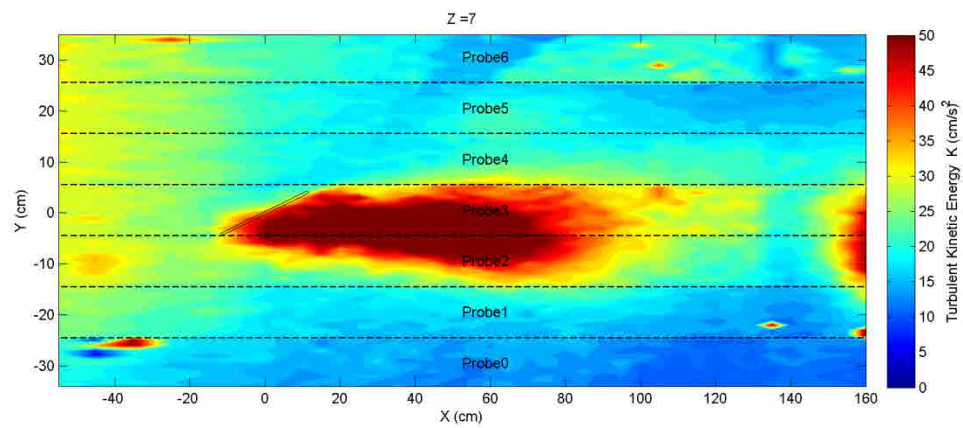
#### 1. Turbulent Kinetic Energy

##### Turbulent Kinetic energy $K$ in x and y-Directions

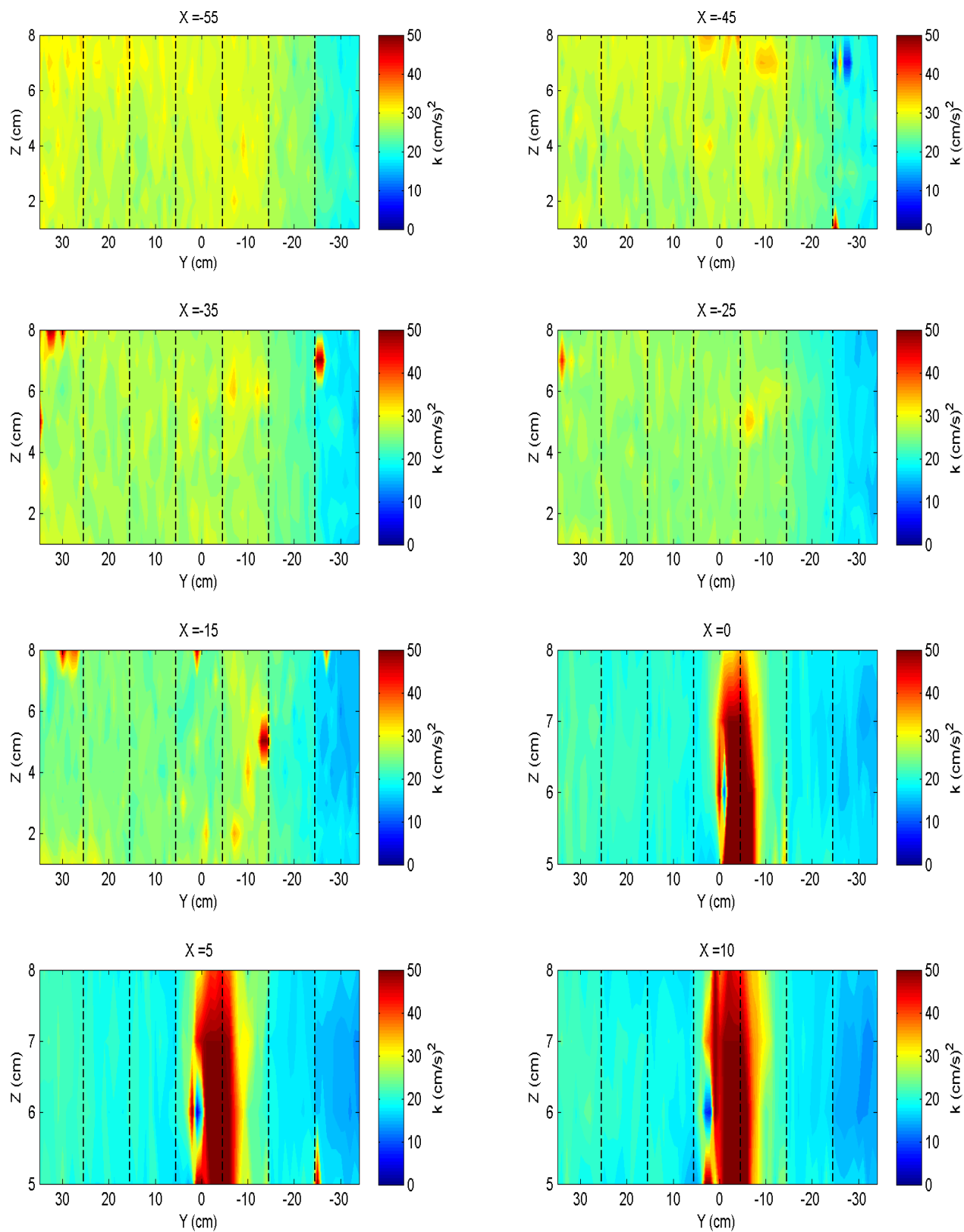


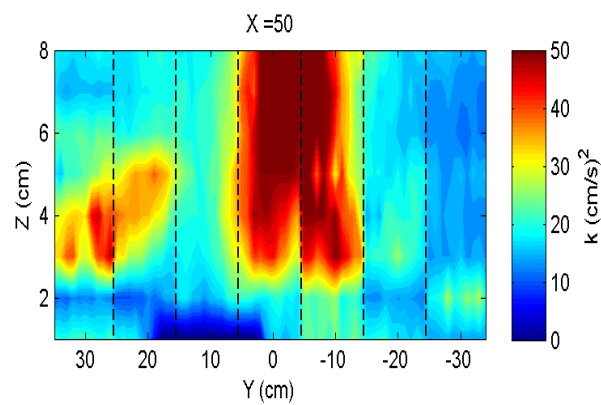
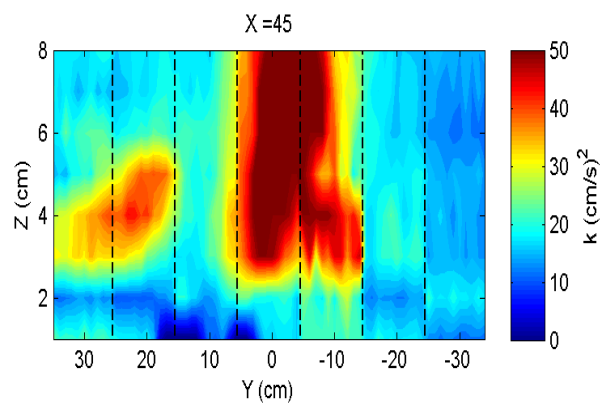
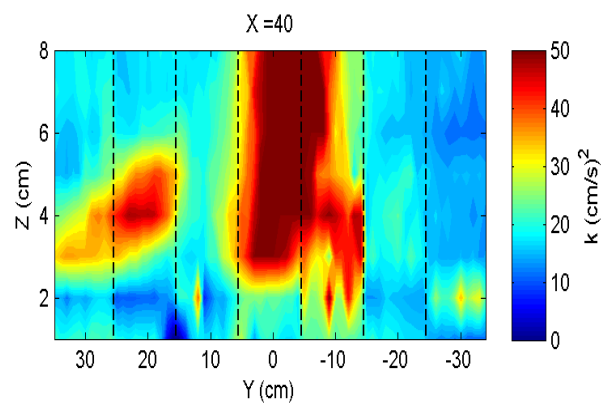
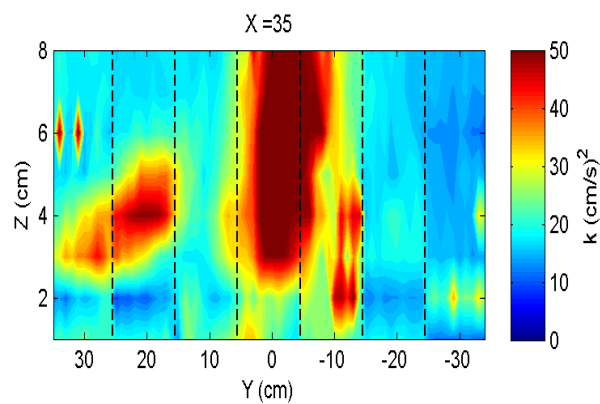
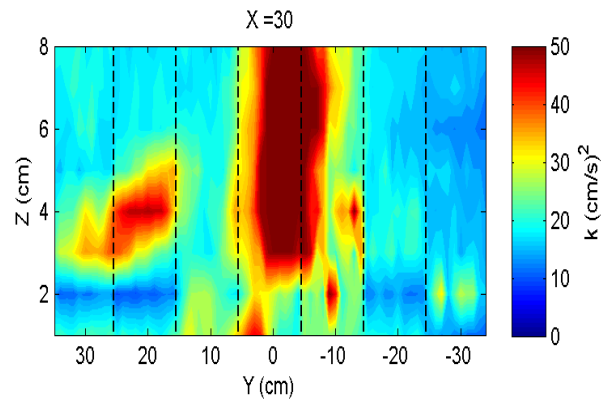
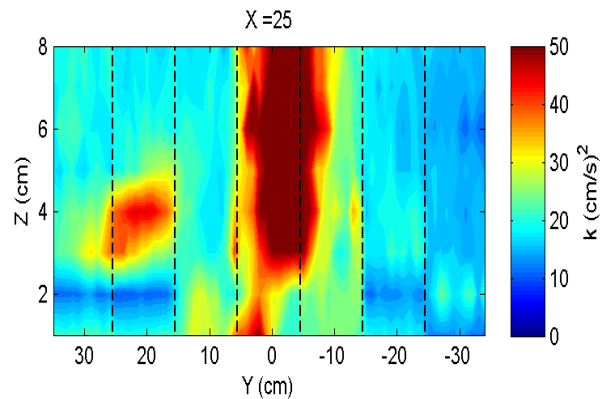
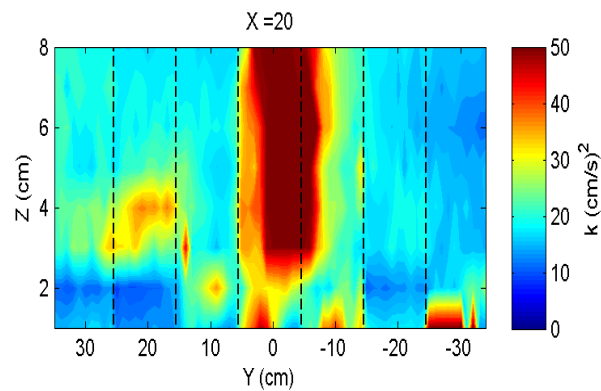
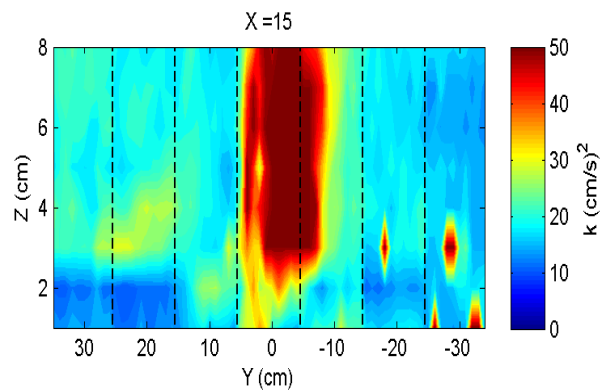


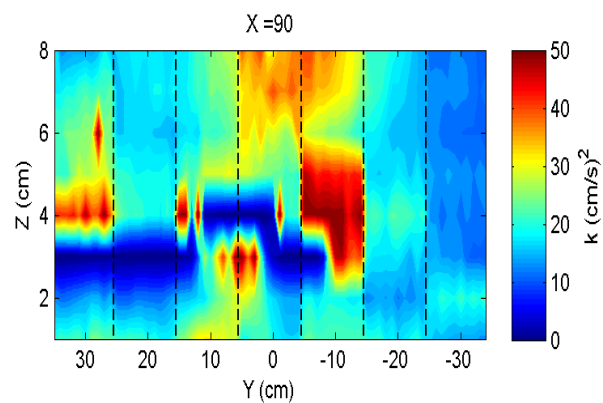
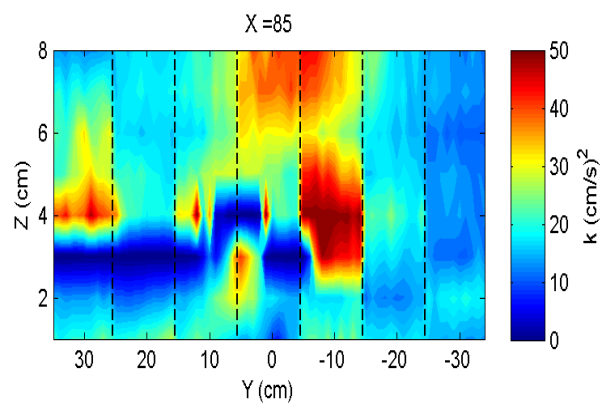
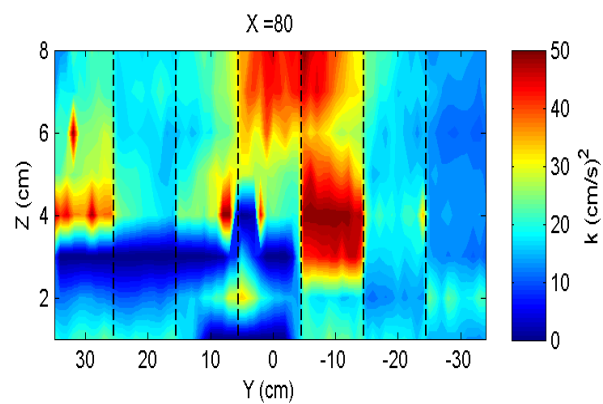
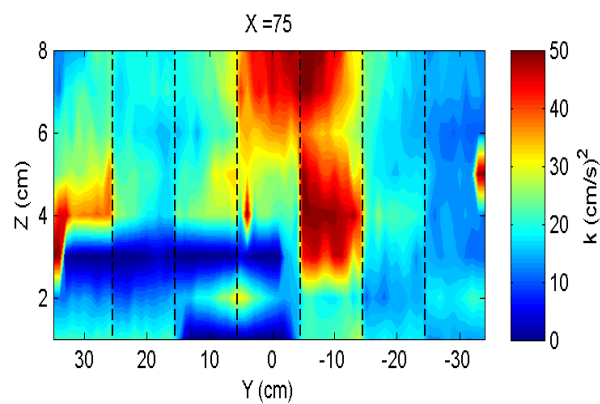
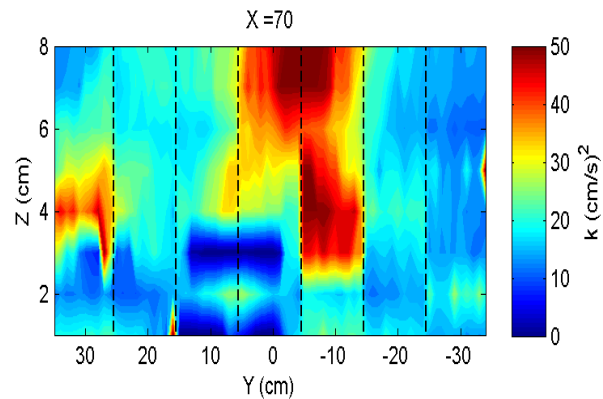
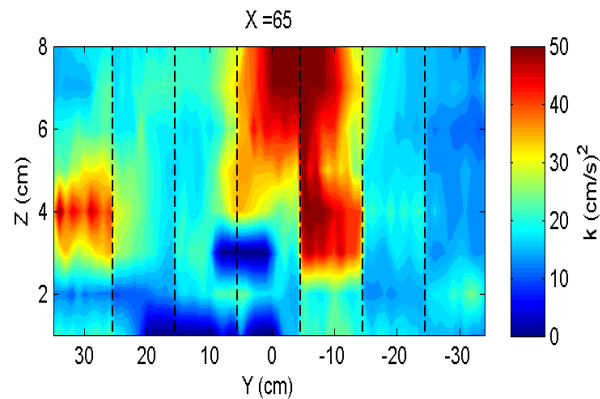
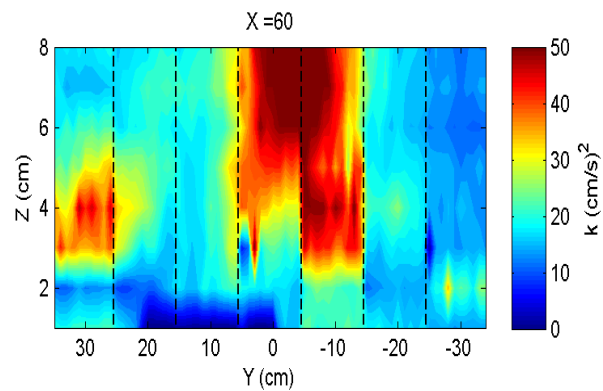
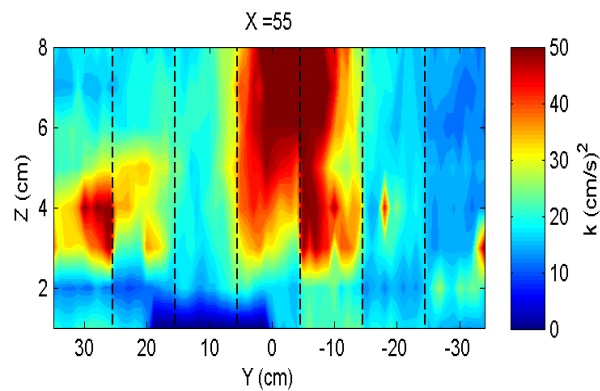




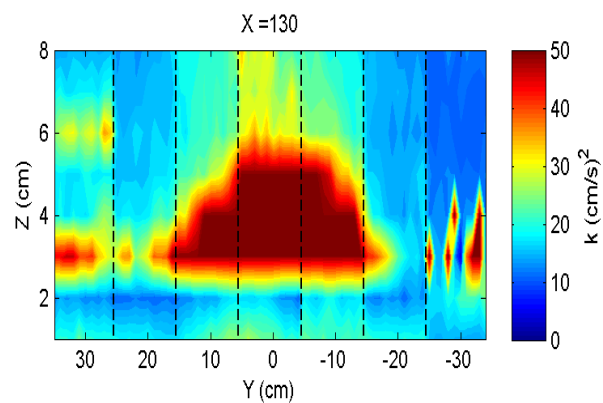
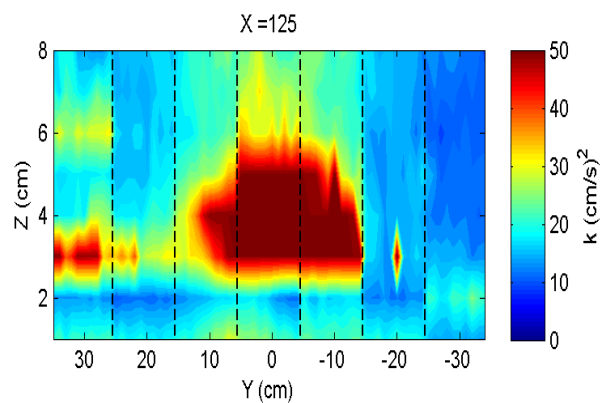
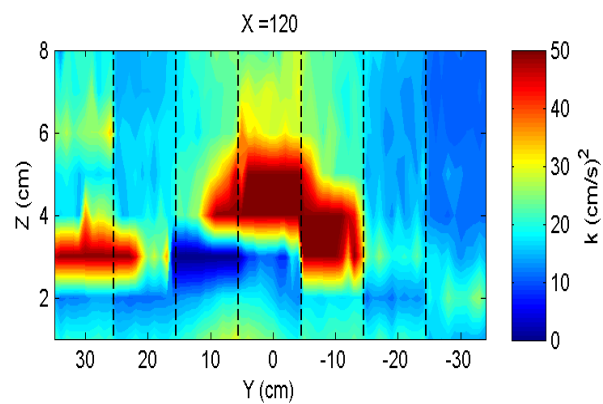
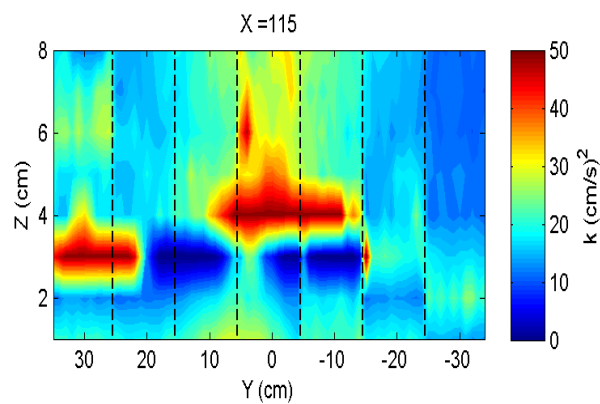
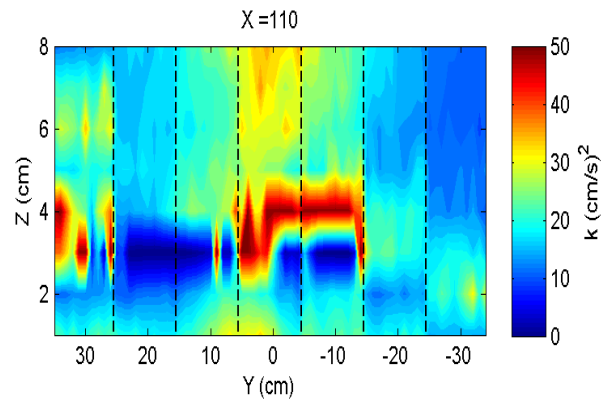
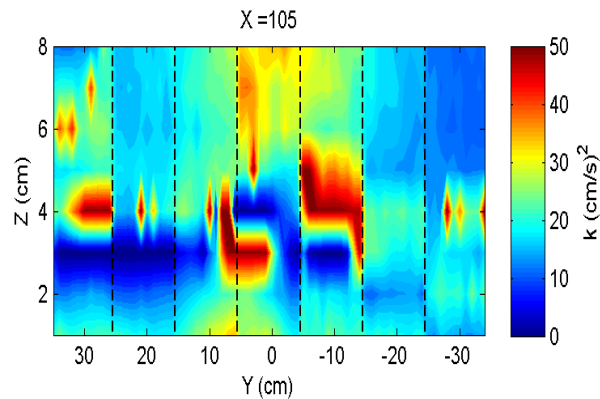
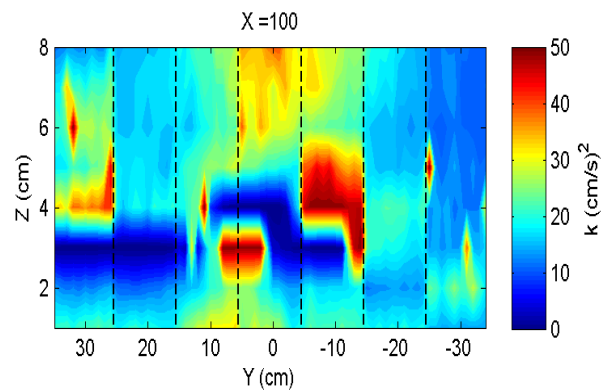
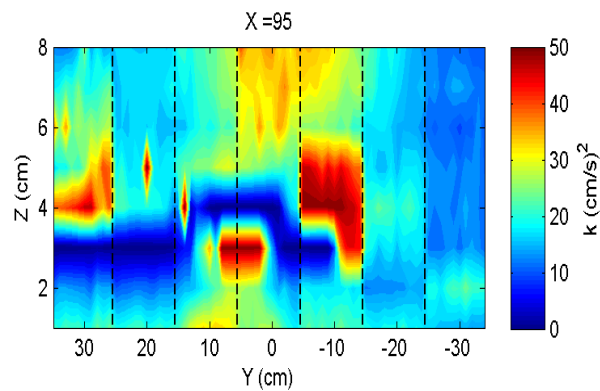
## Turbulent Kinetic Energy $K$ in y and z-Directions

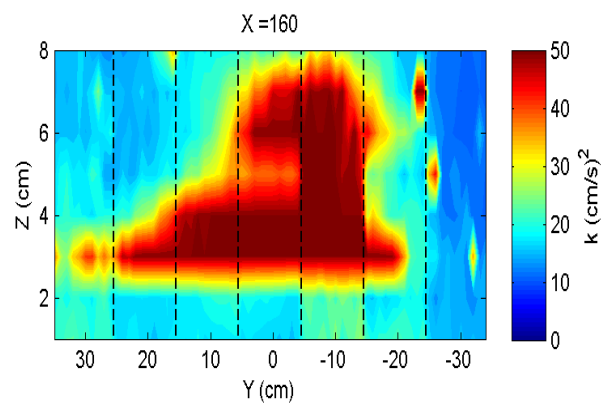
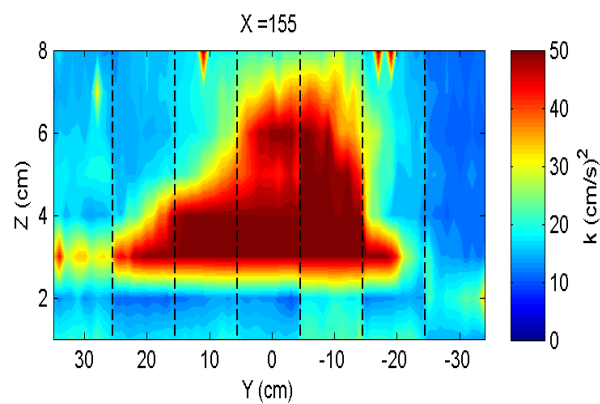
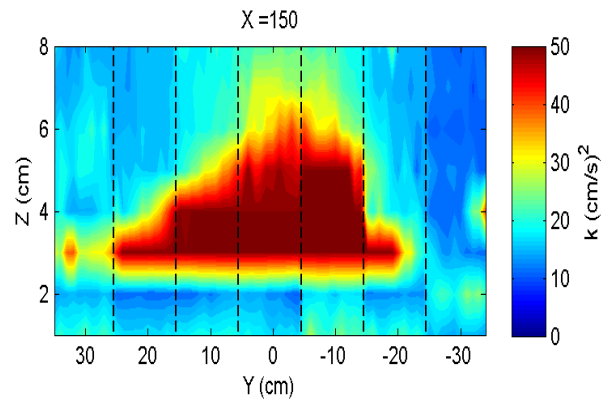
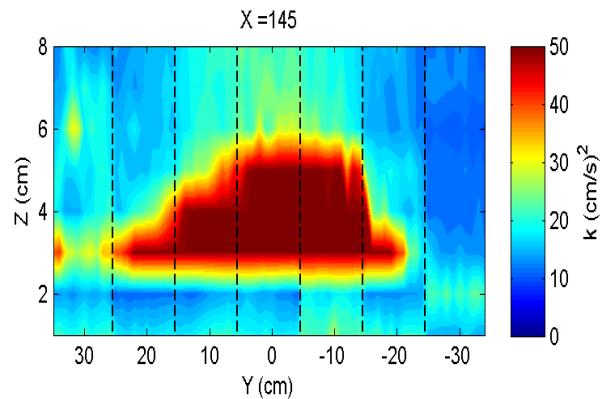
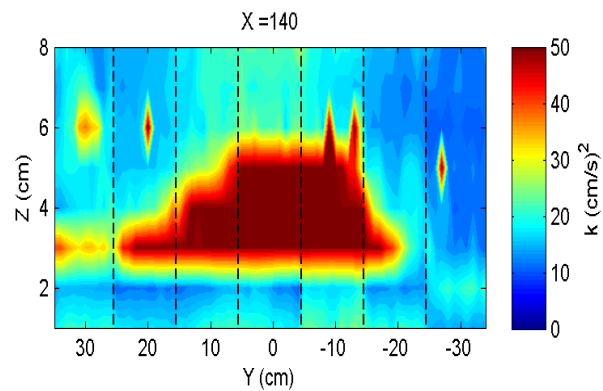
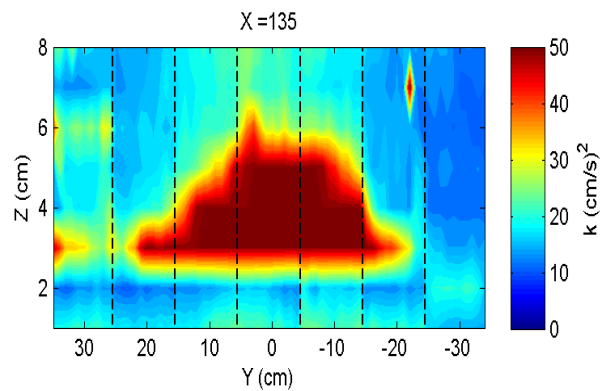




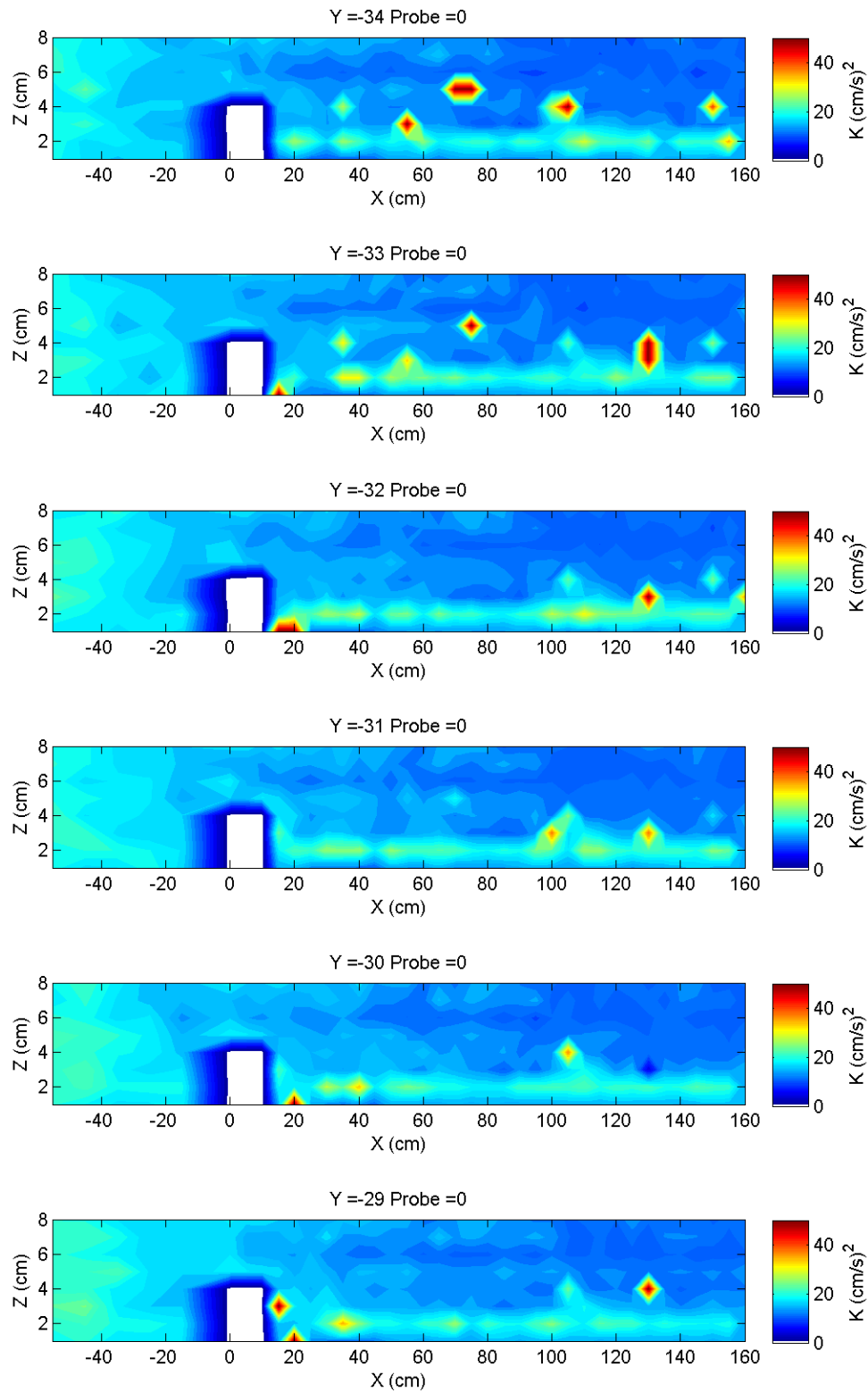




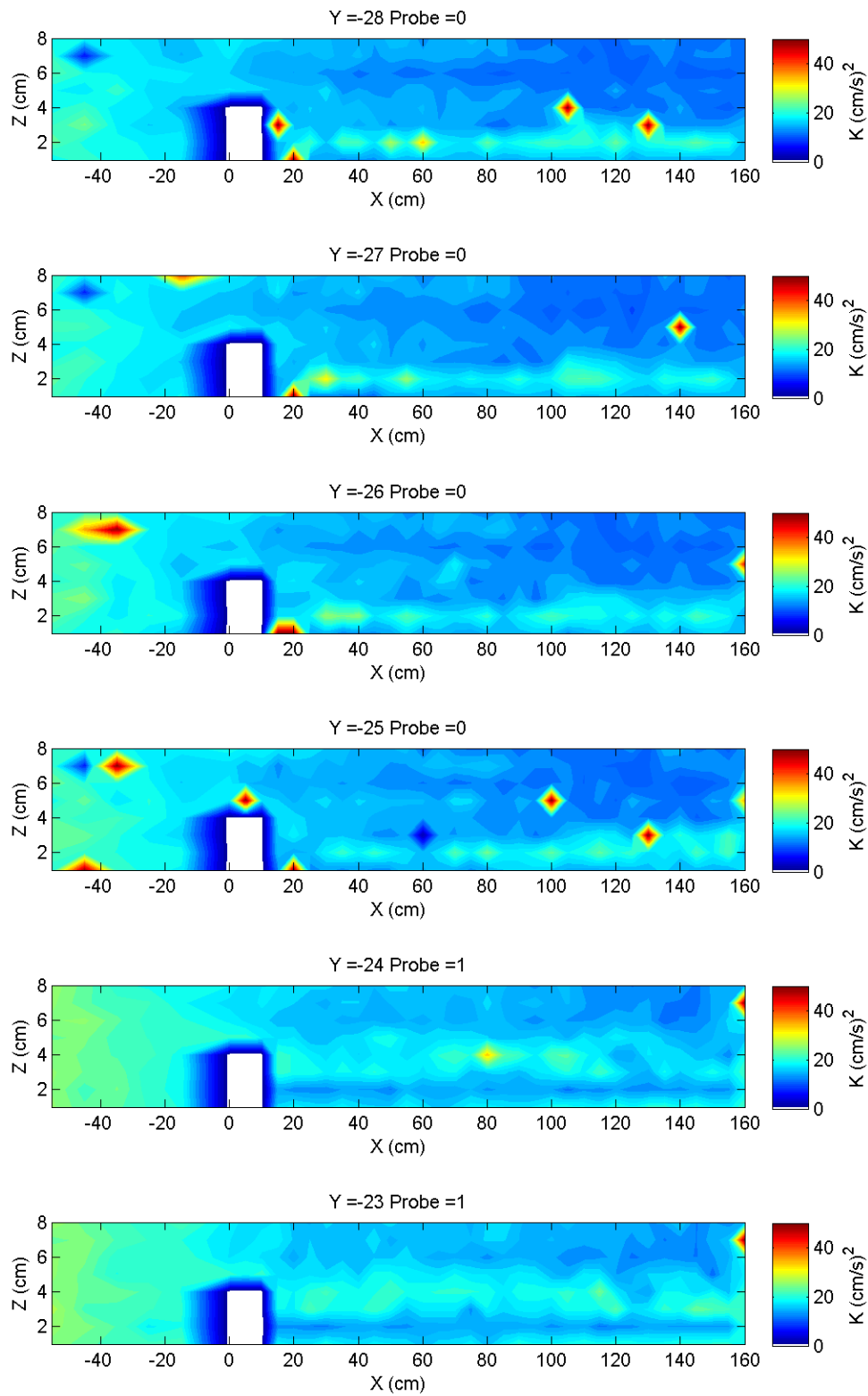


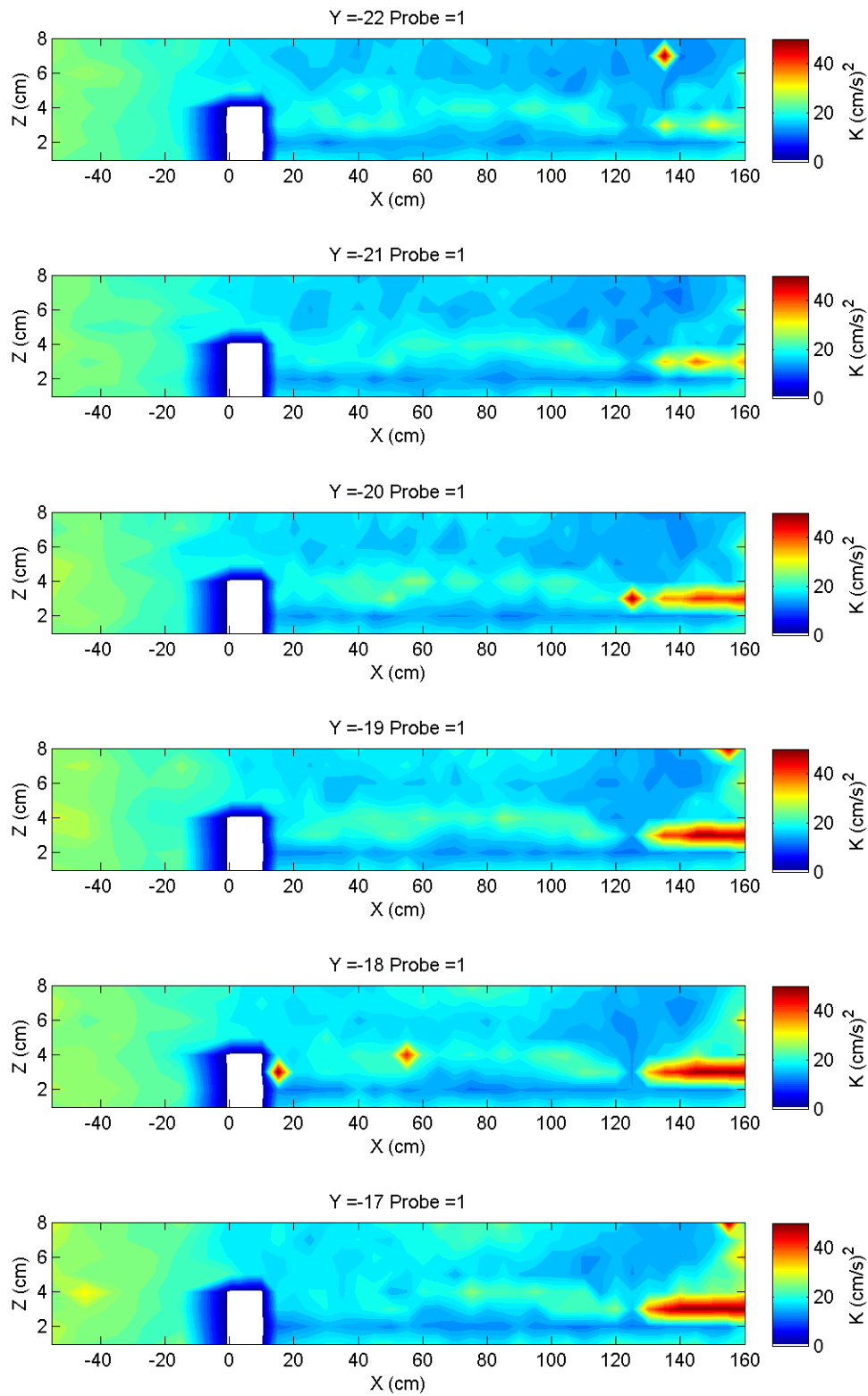


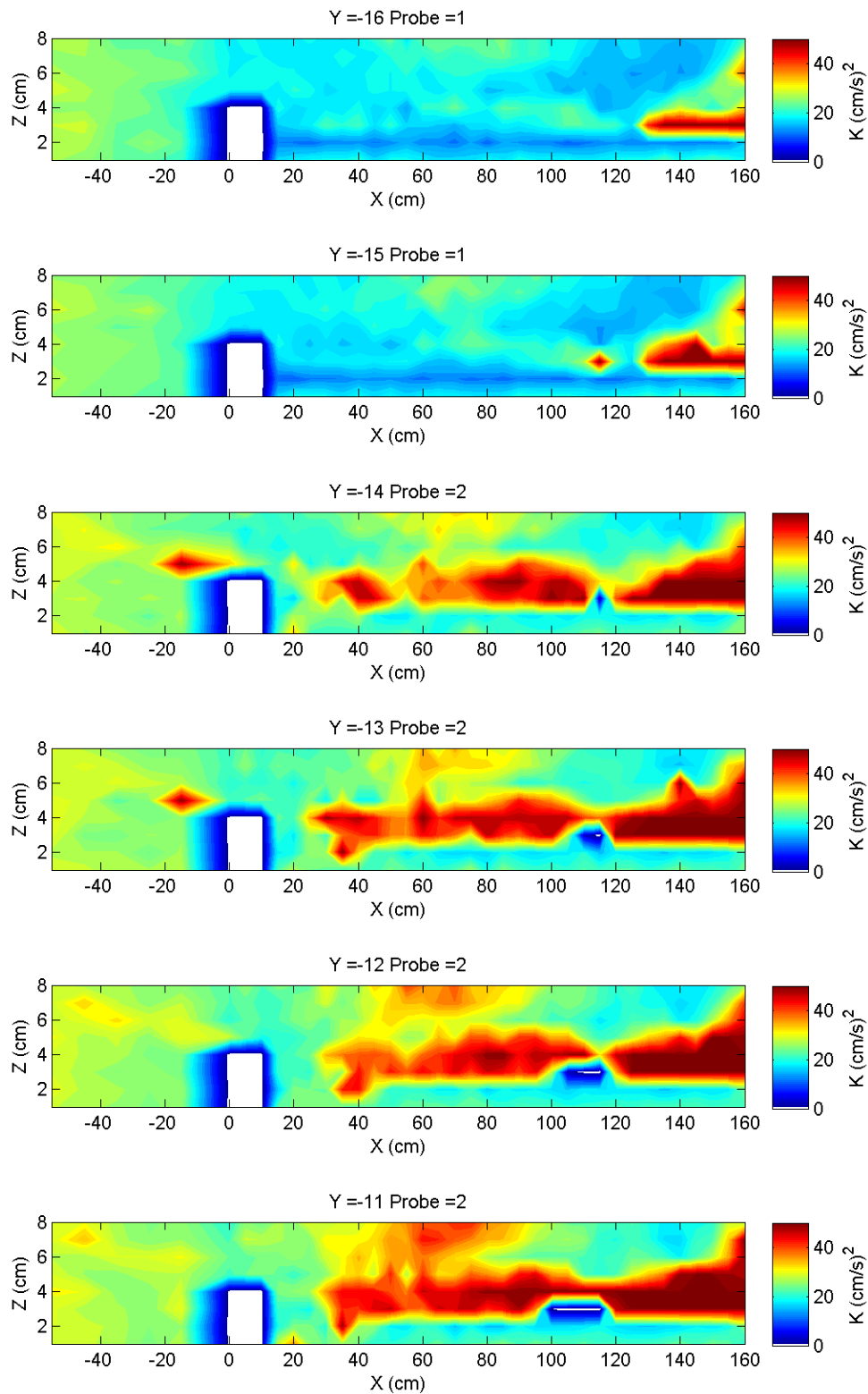
## Turbulent Kinetic Energy $K$ in x and z-Directions

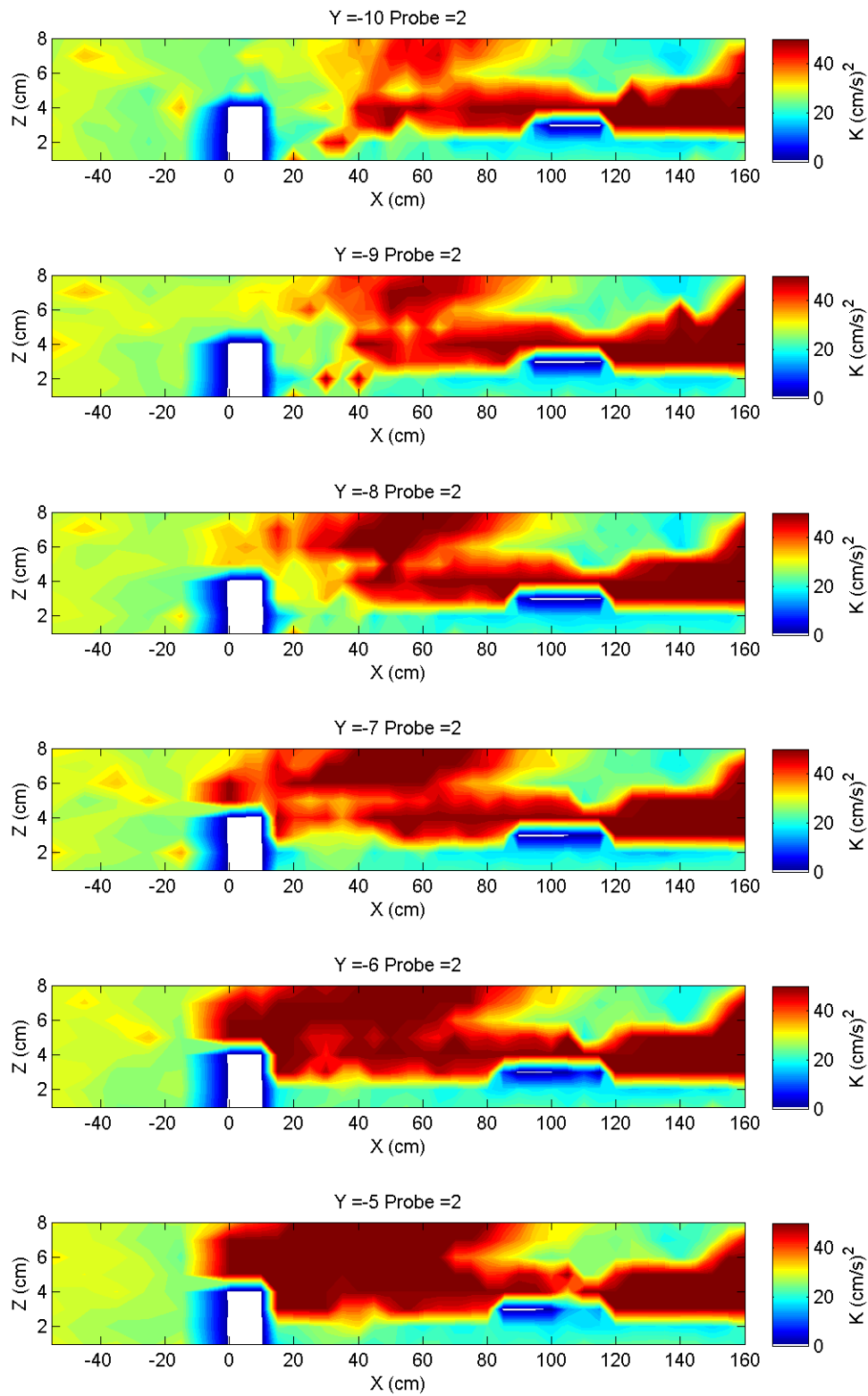


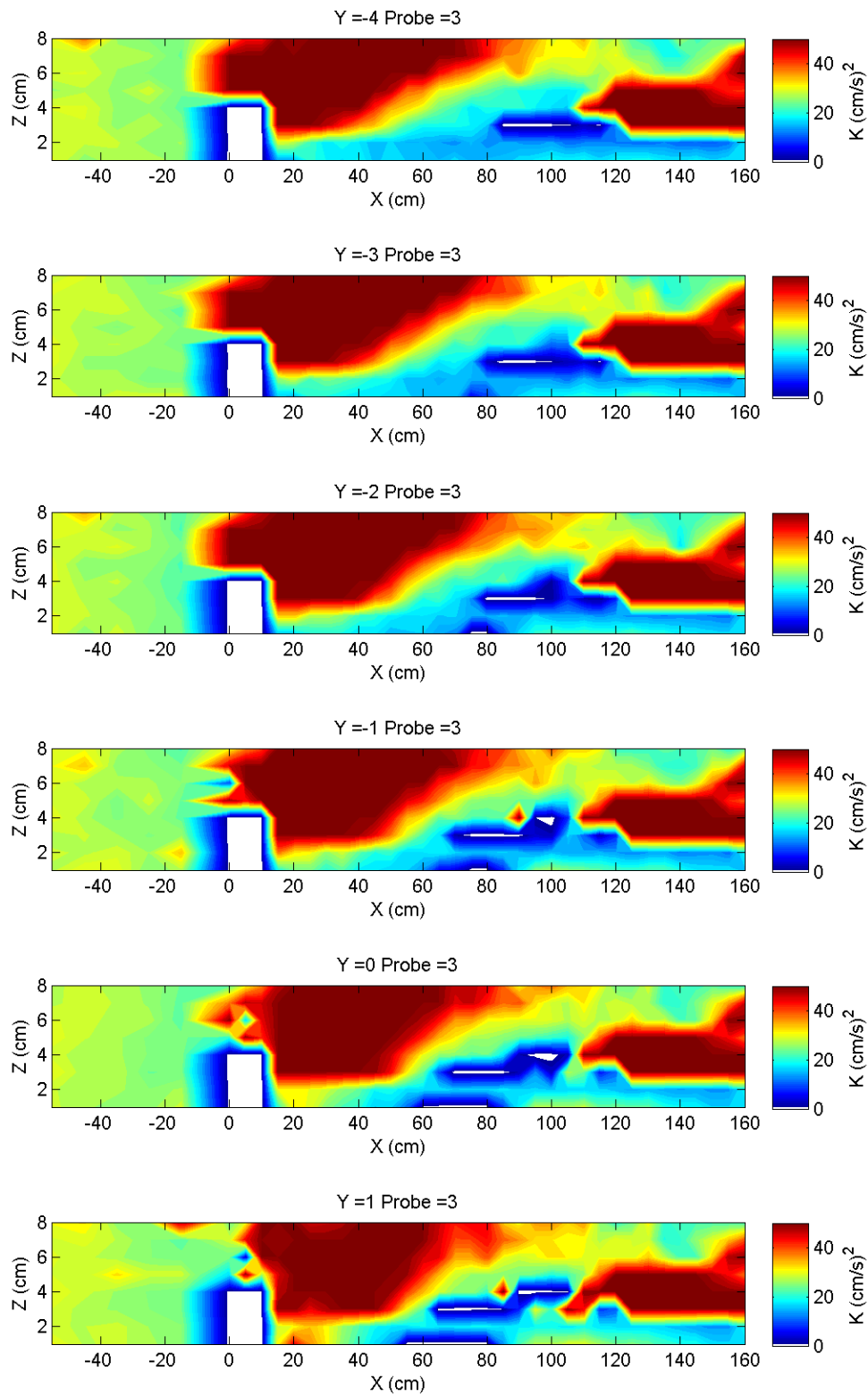


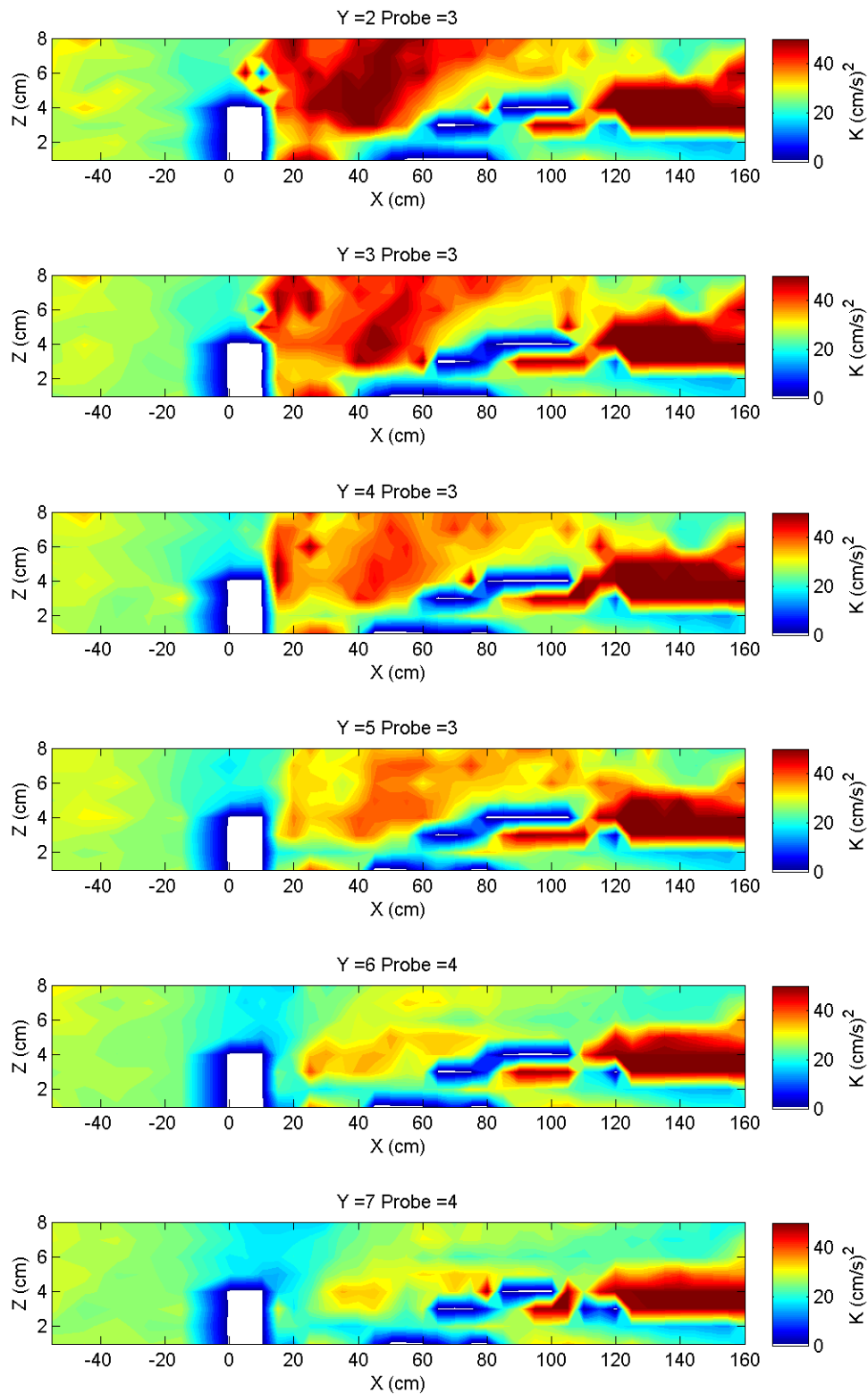


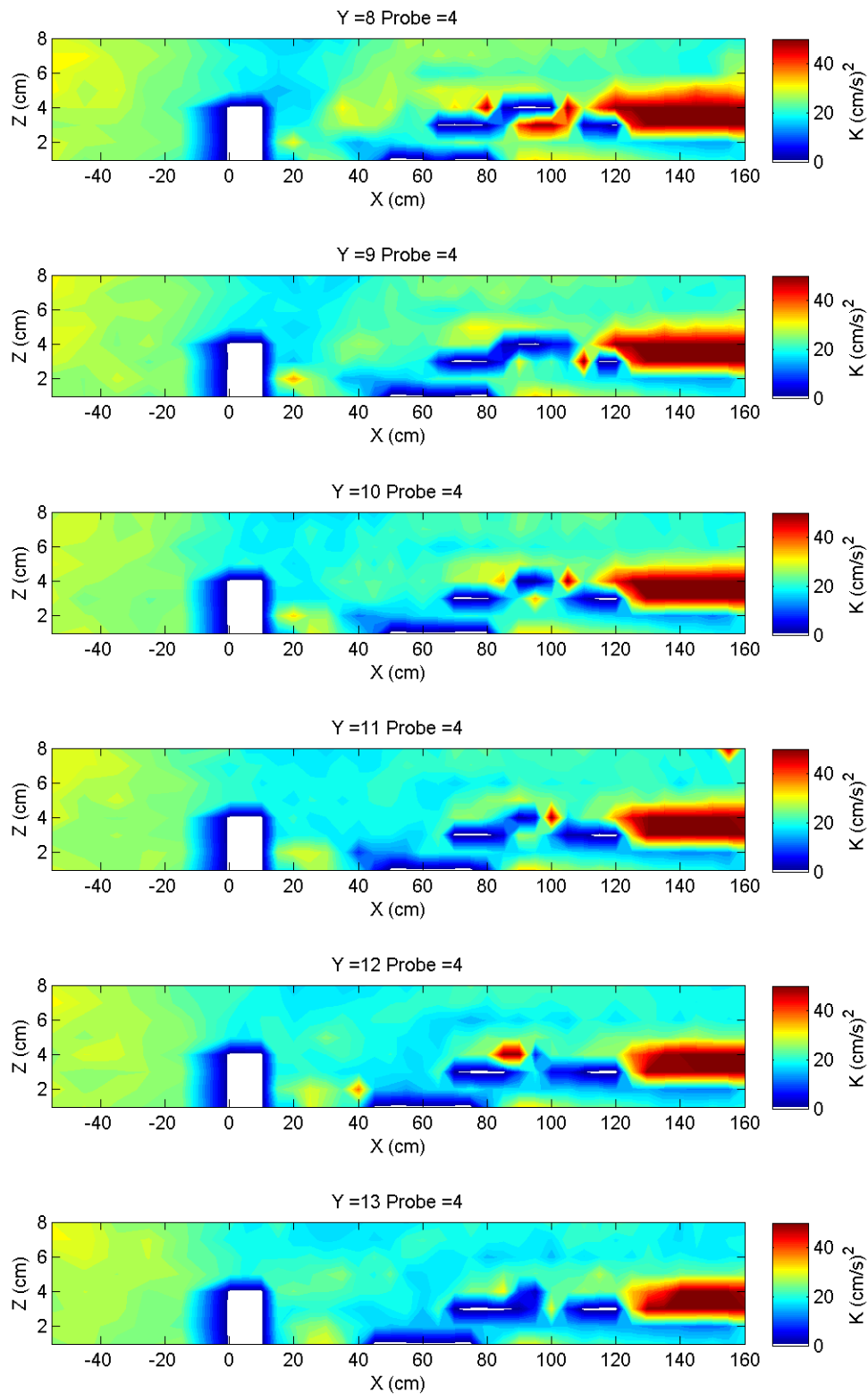


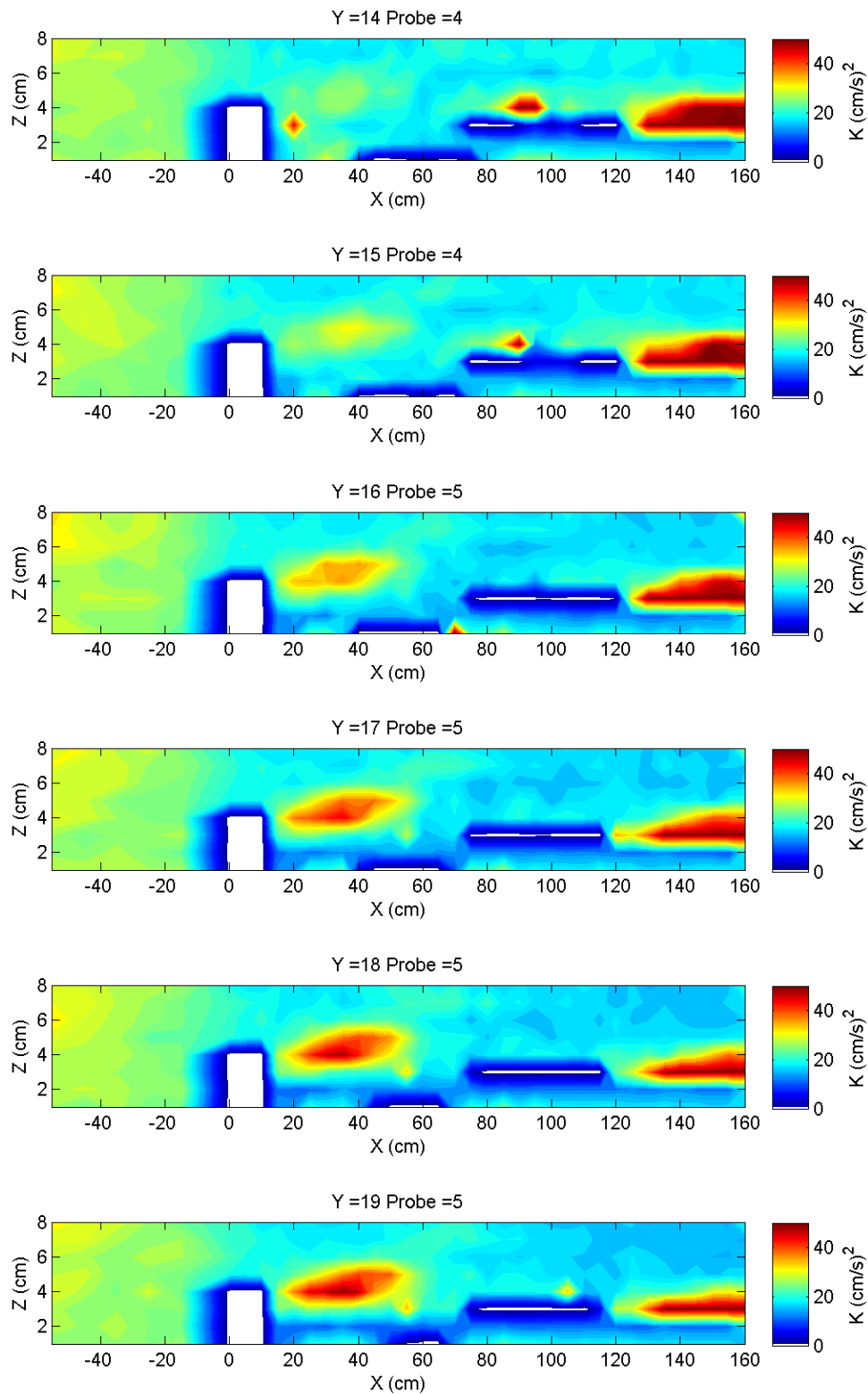




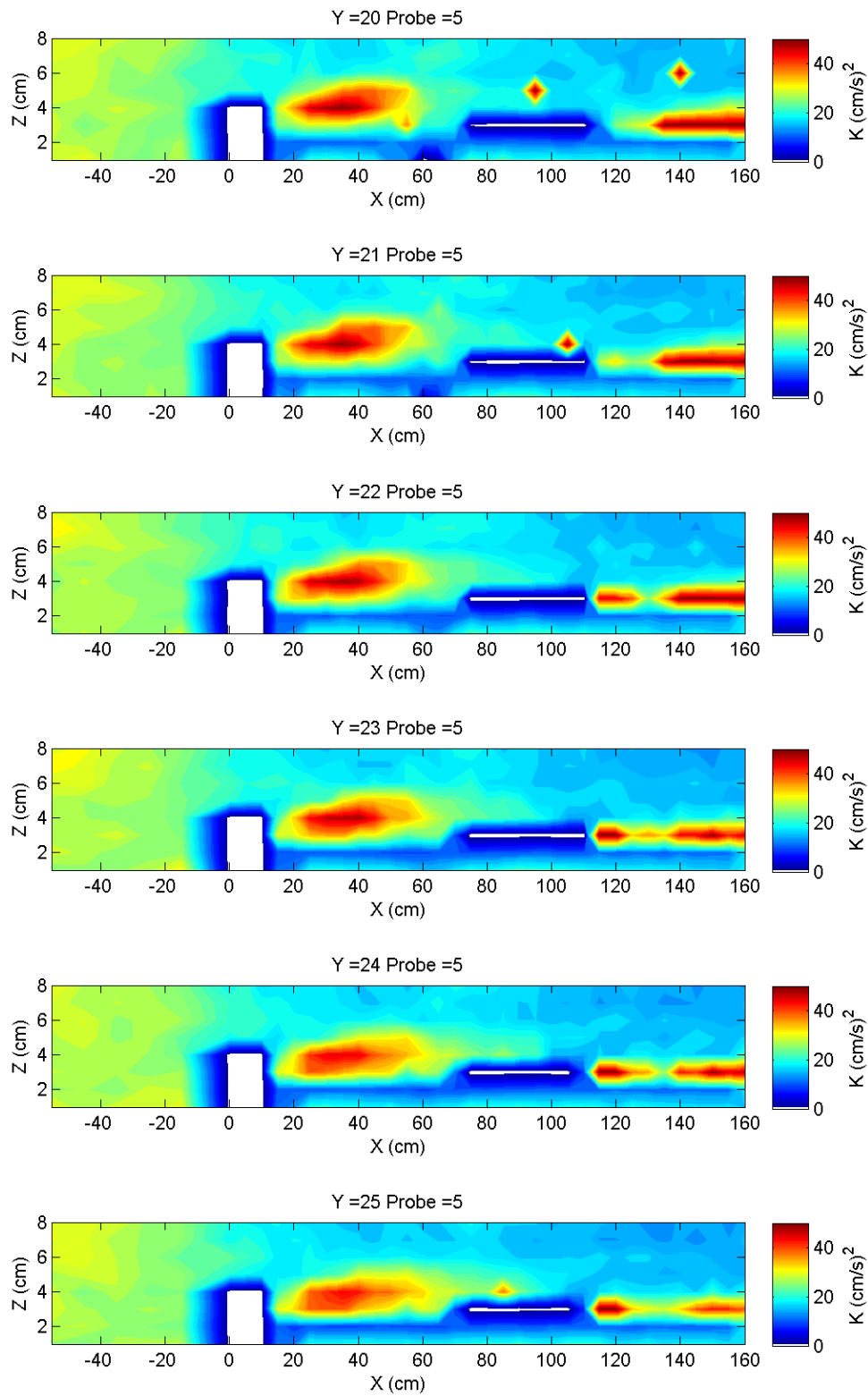


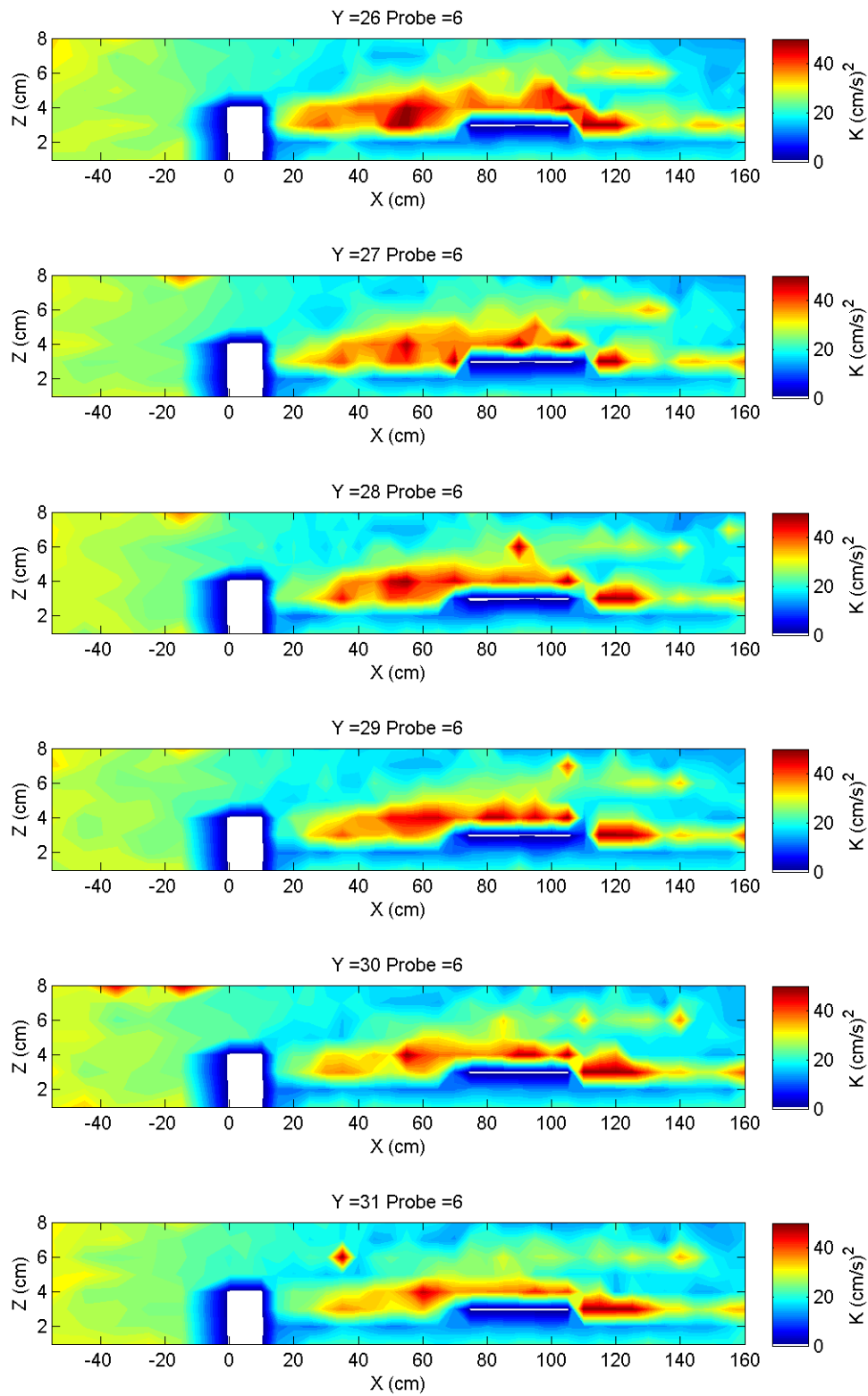


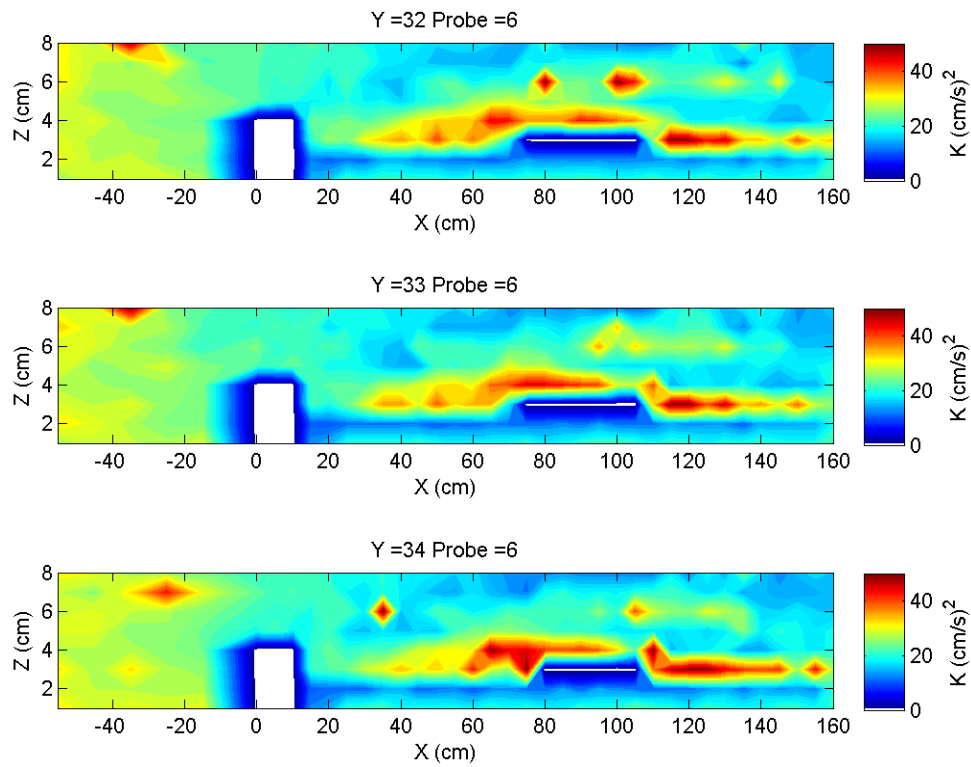






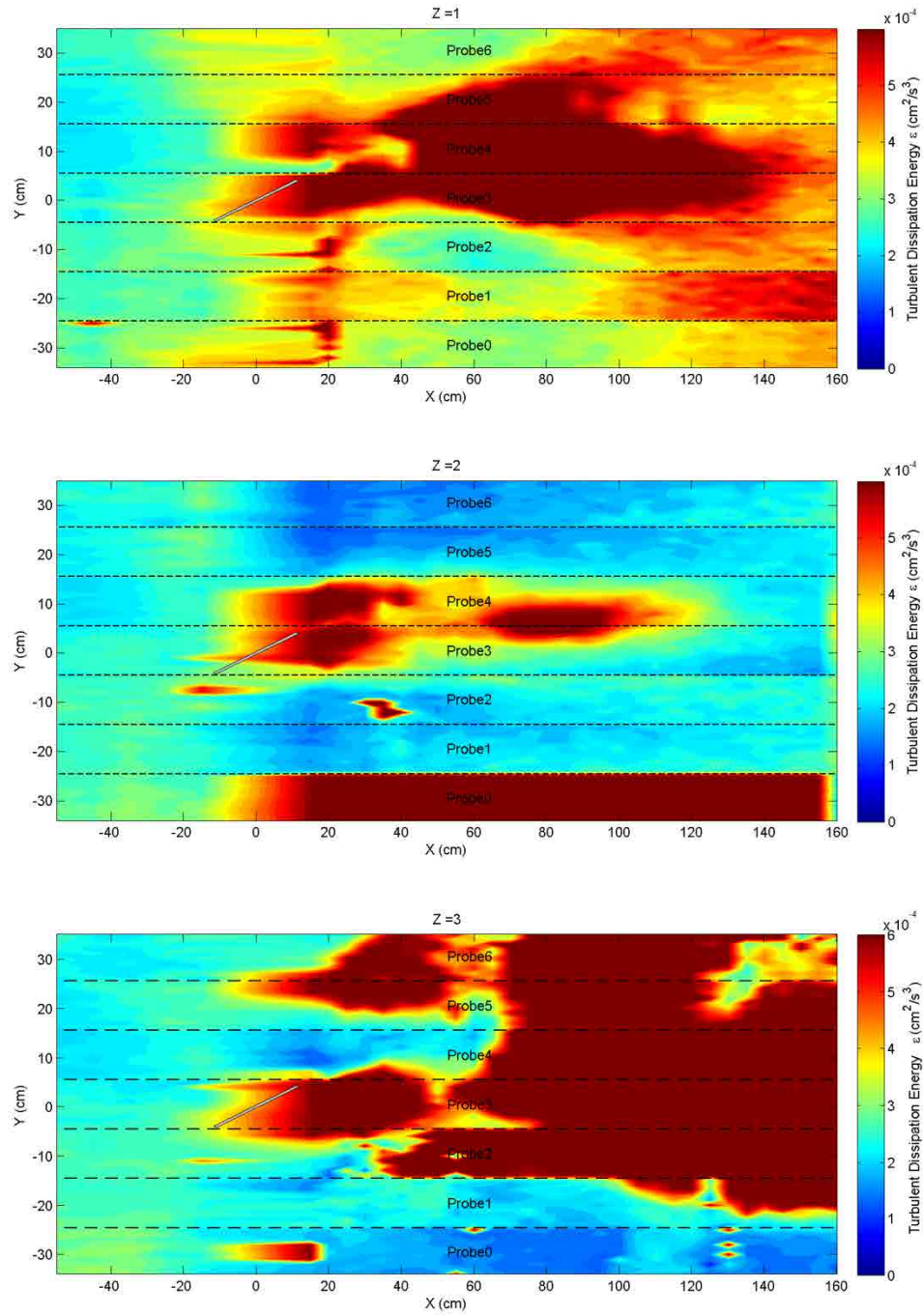


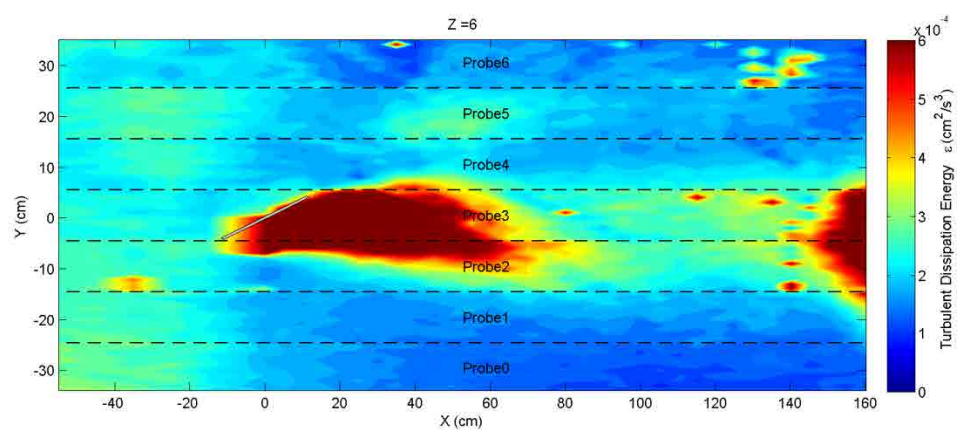
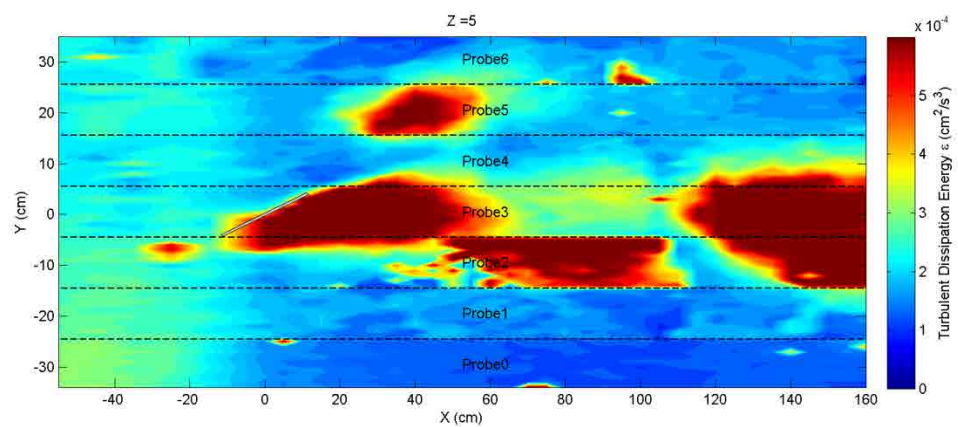
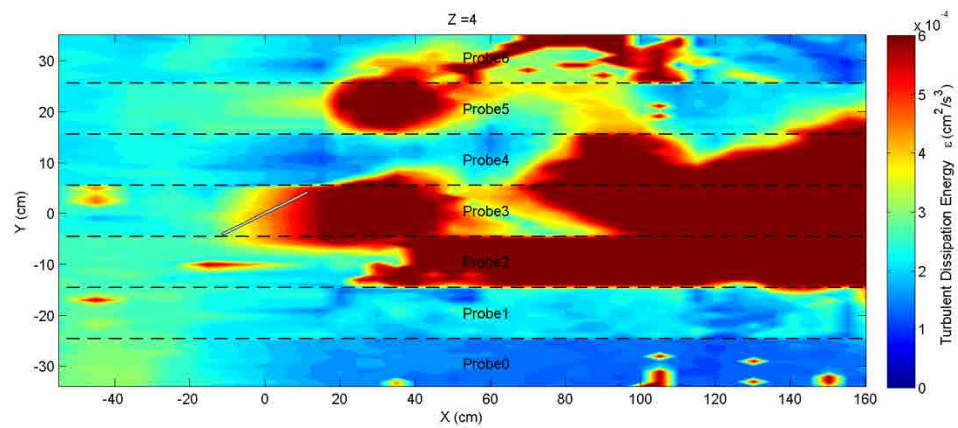




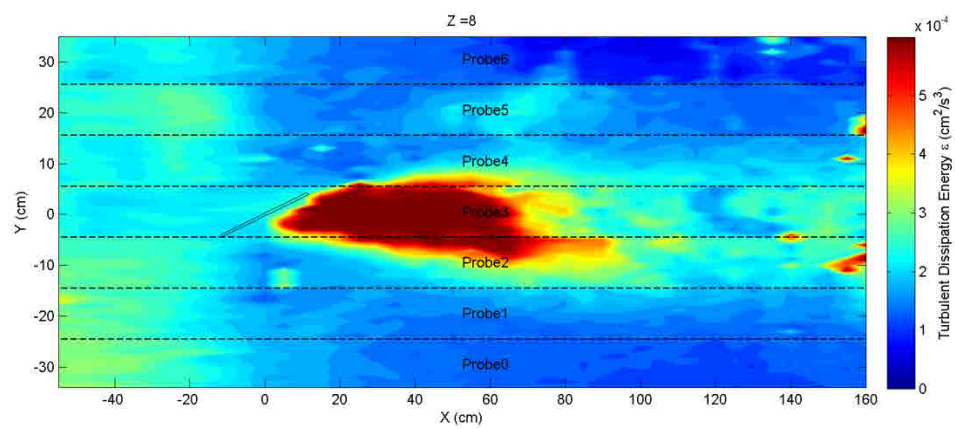
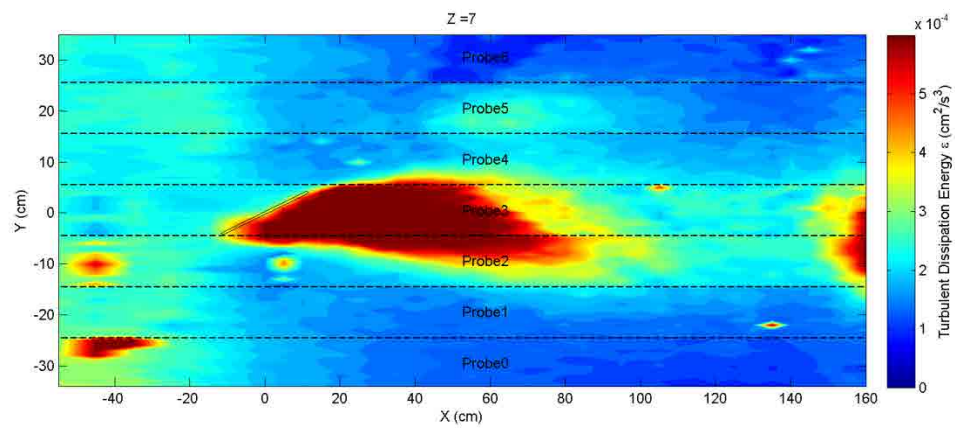
## 2. Turbulent Dissipation Energy

### Turbulent Dissipation Energy $\varepsilon$ in x and y-Directions

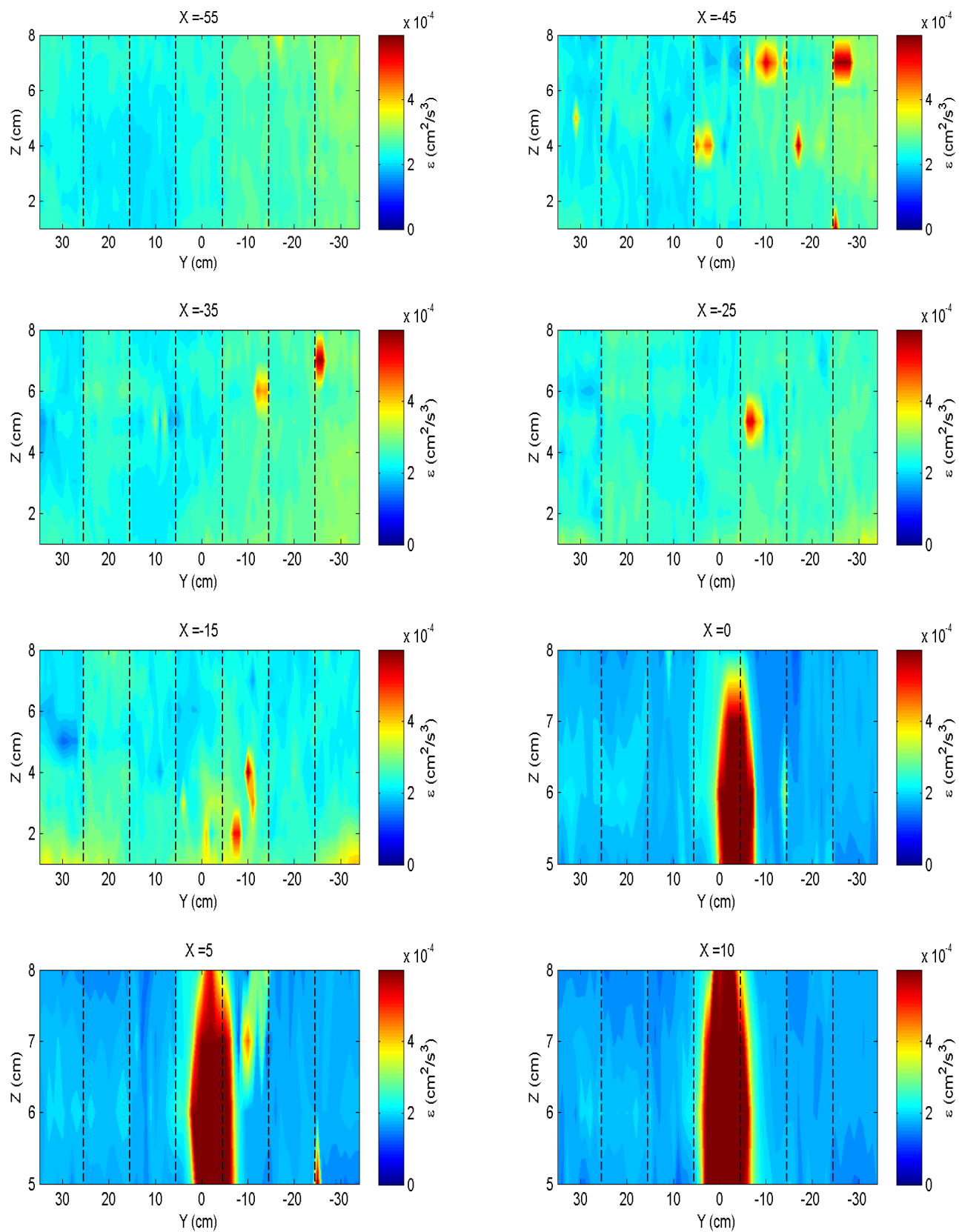


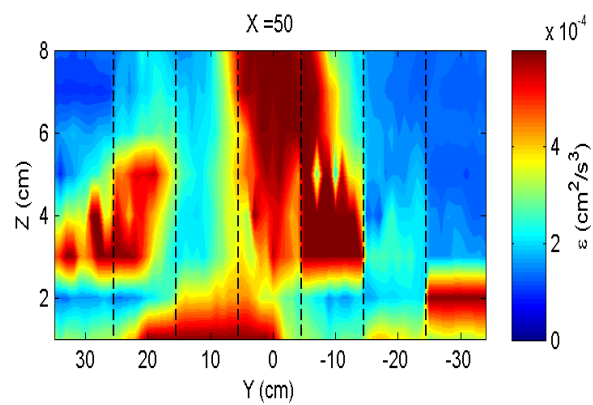
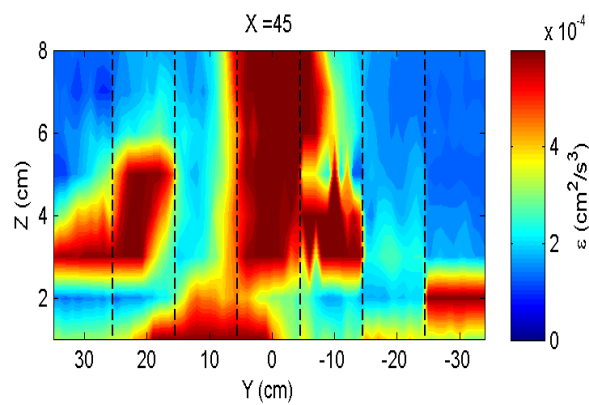
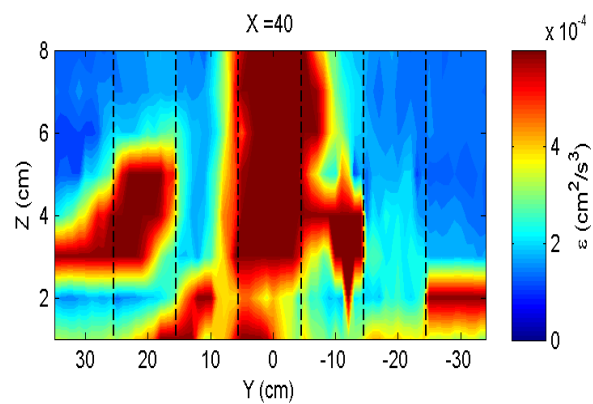
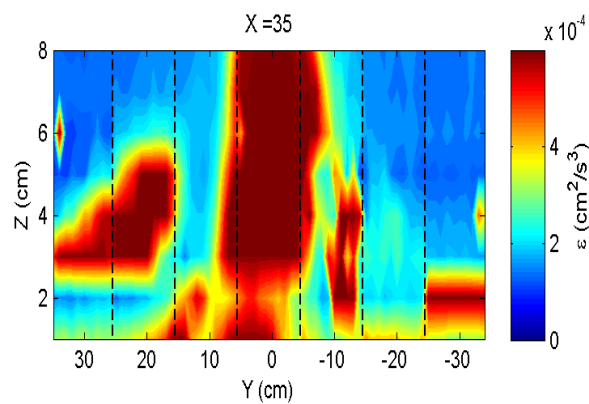
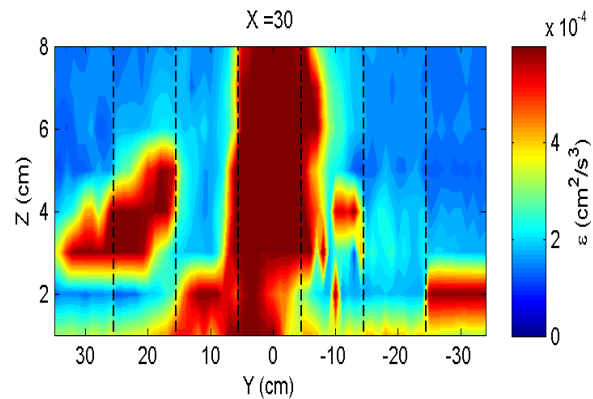
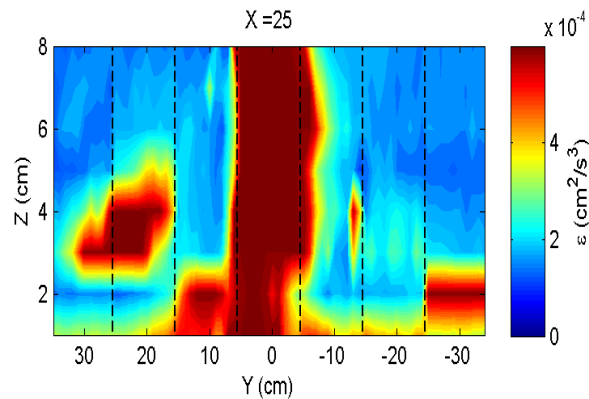
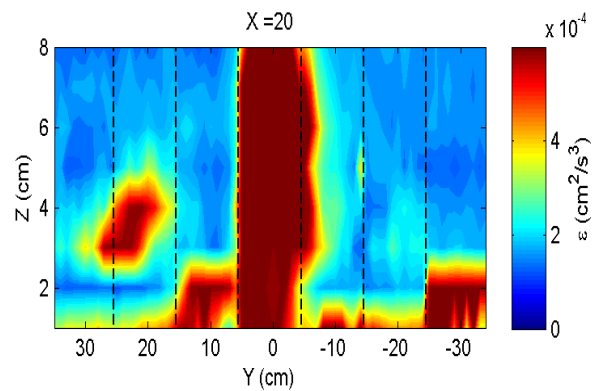
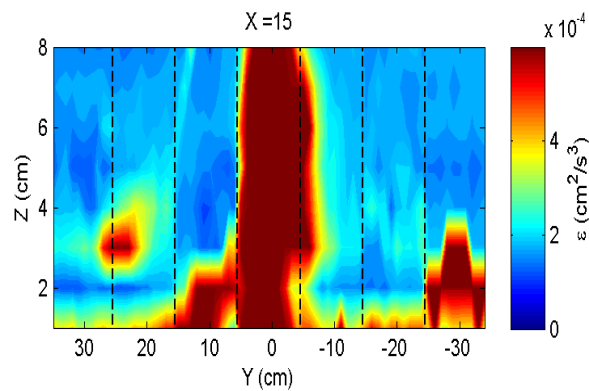




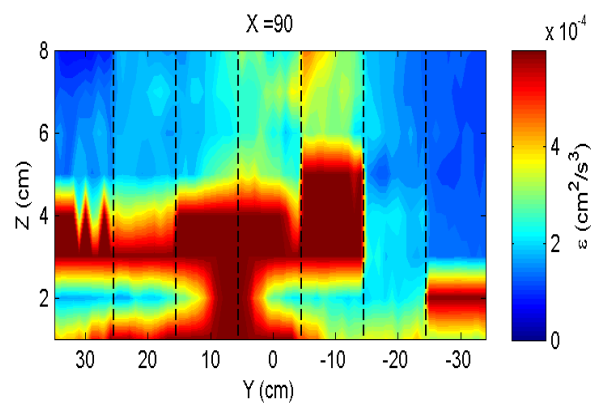
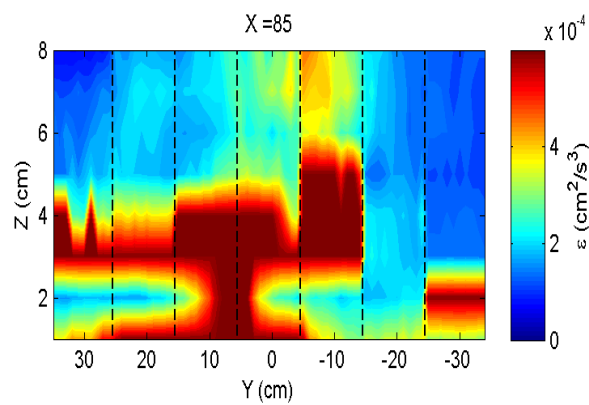
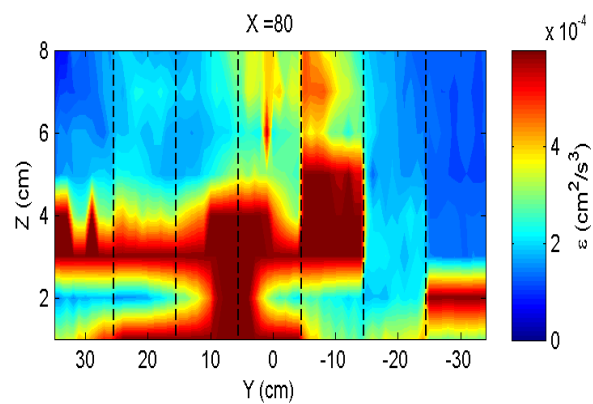
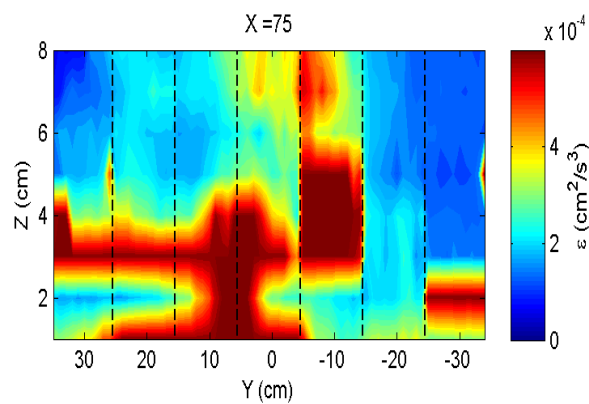
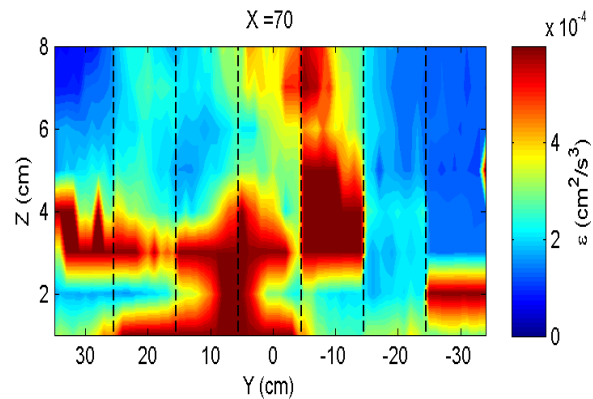
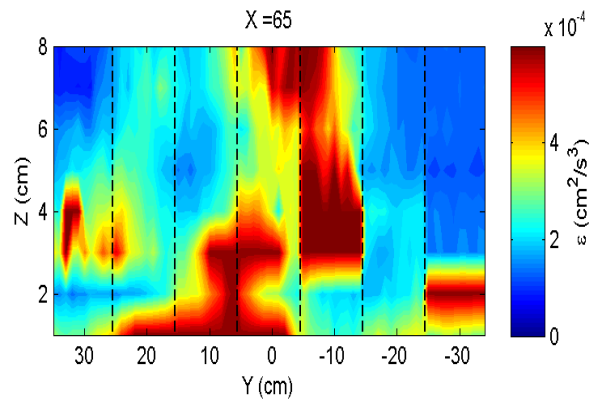
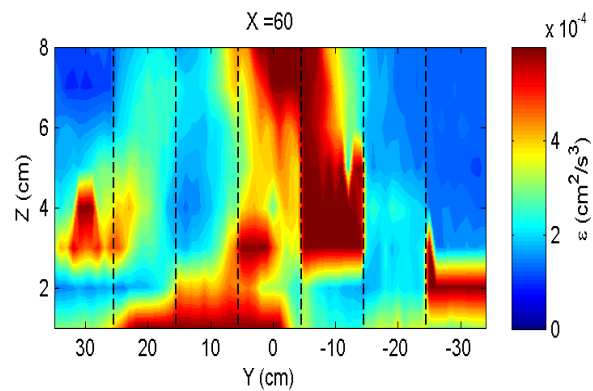
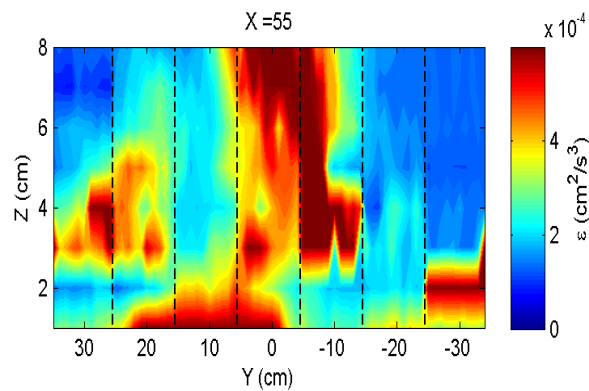


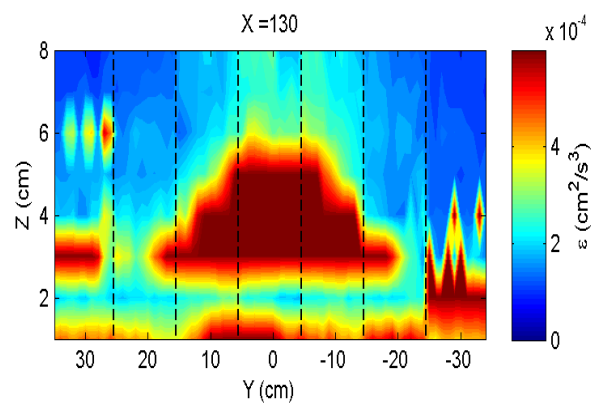
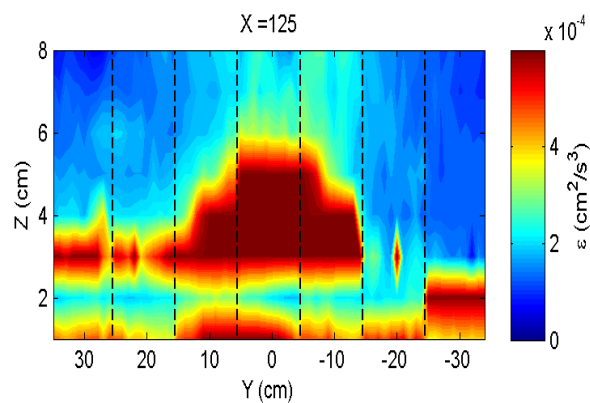
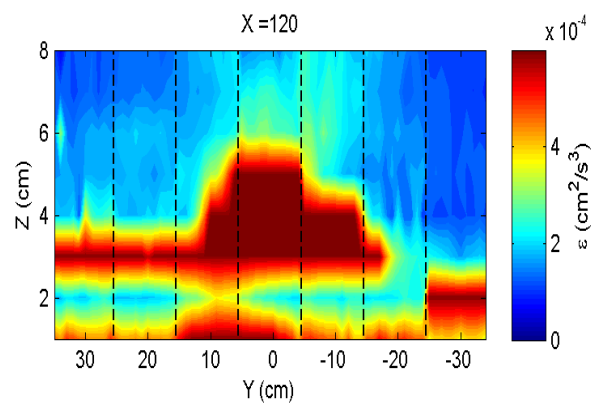
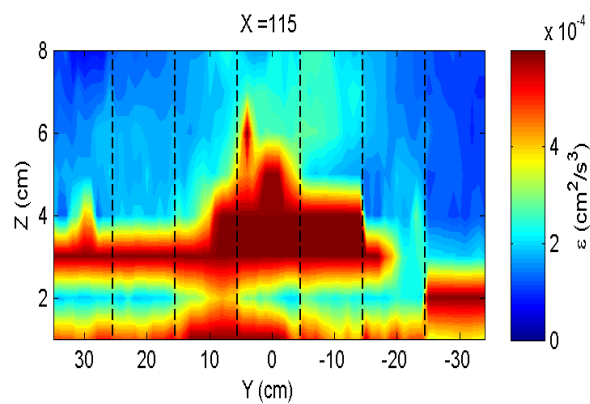
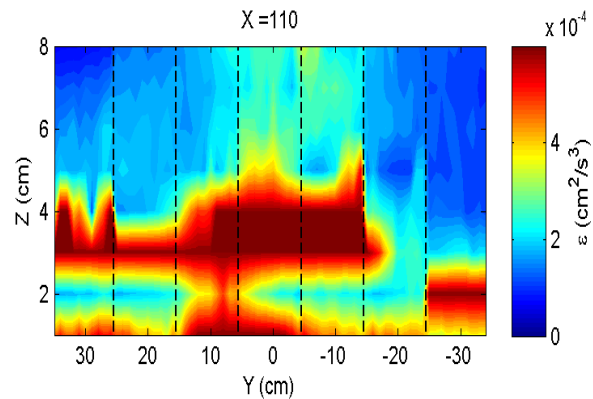
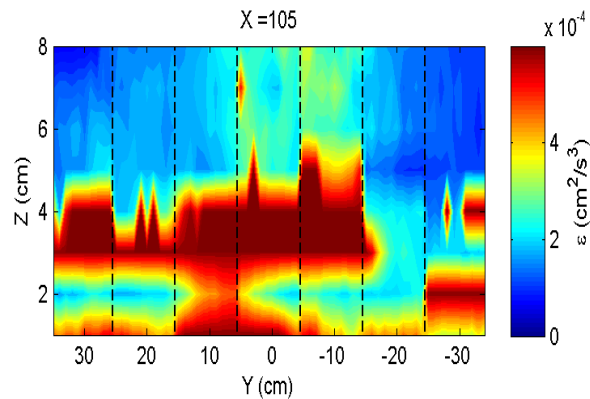
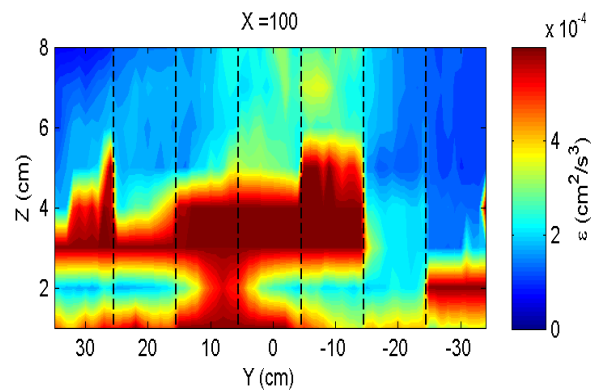
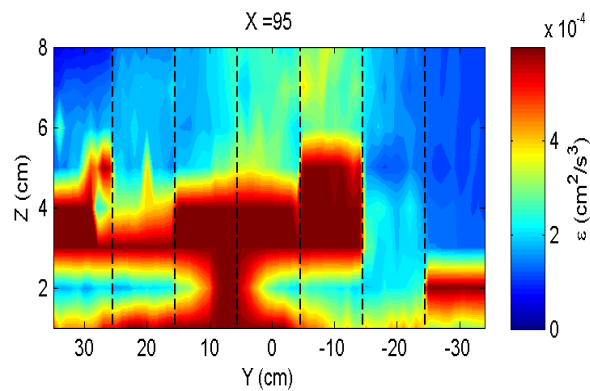
## Turbulent Dissipation Energy $\varepsilon$ in y and z-Directions

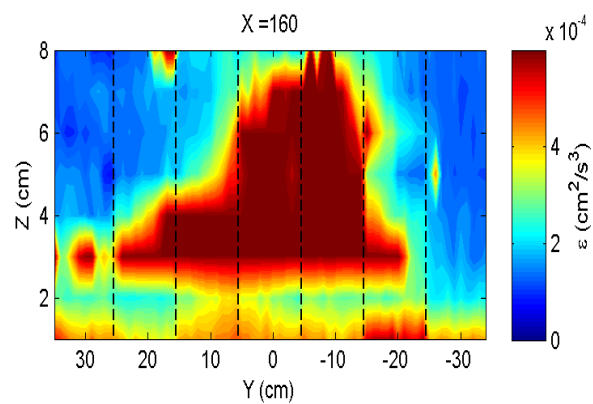
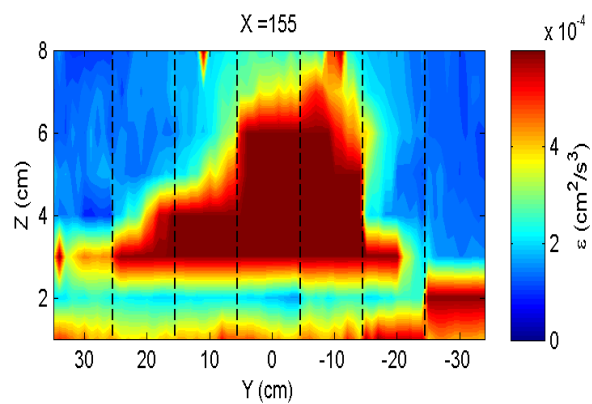
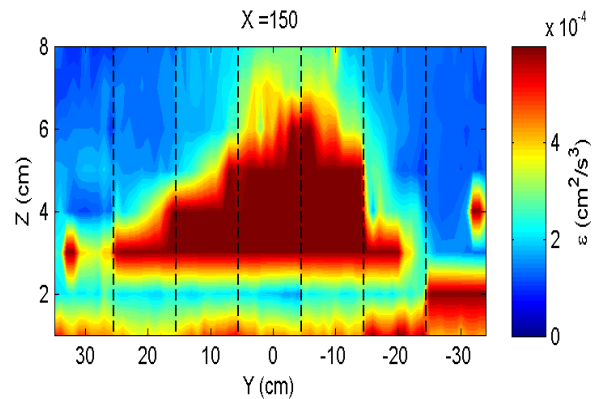
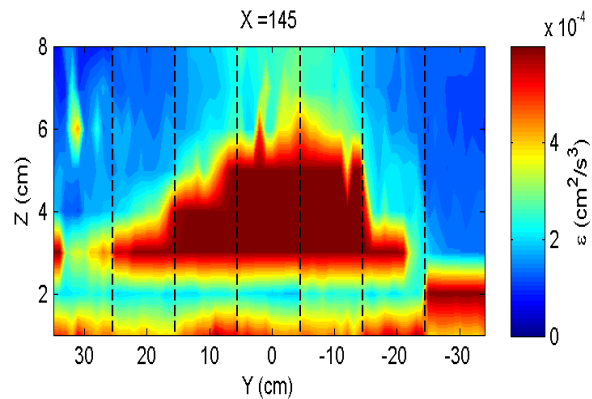
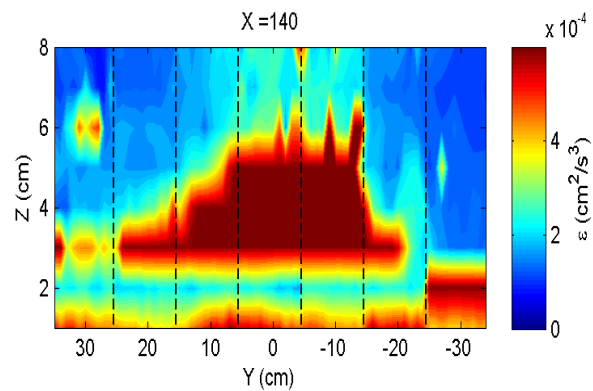
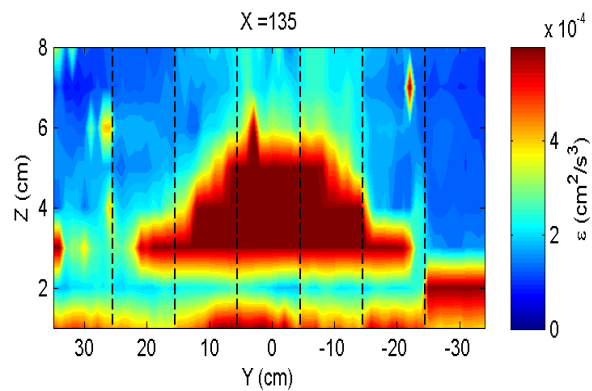




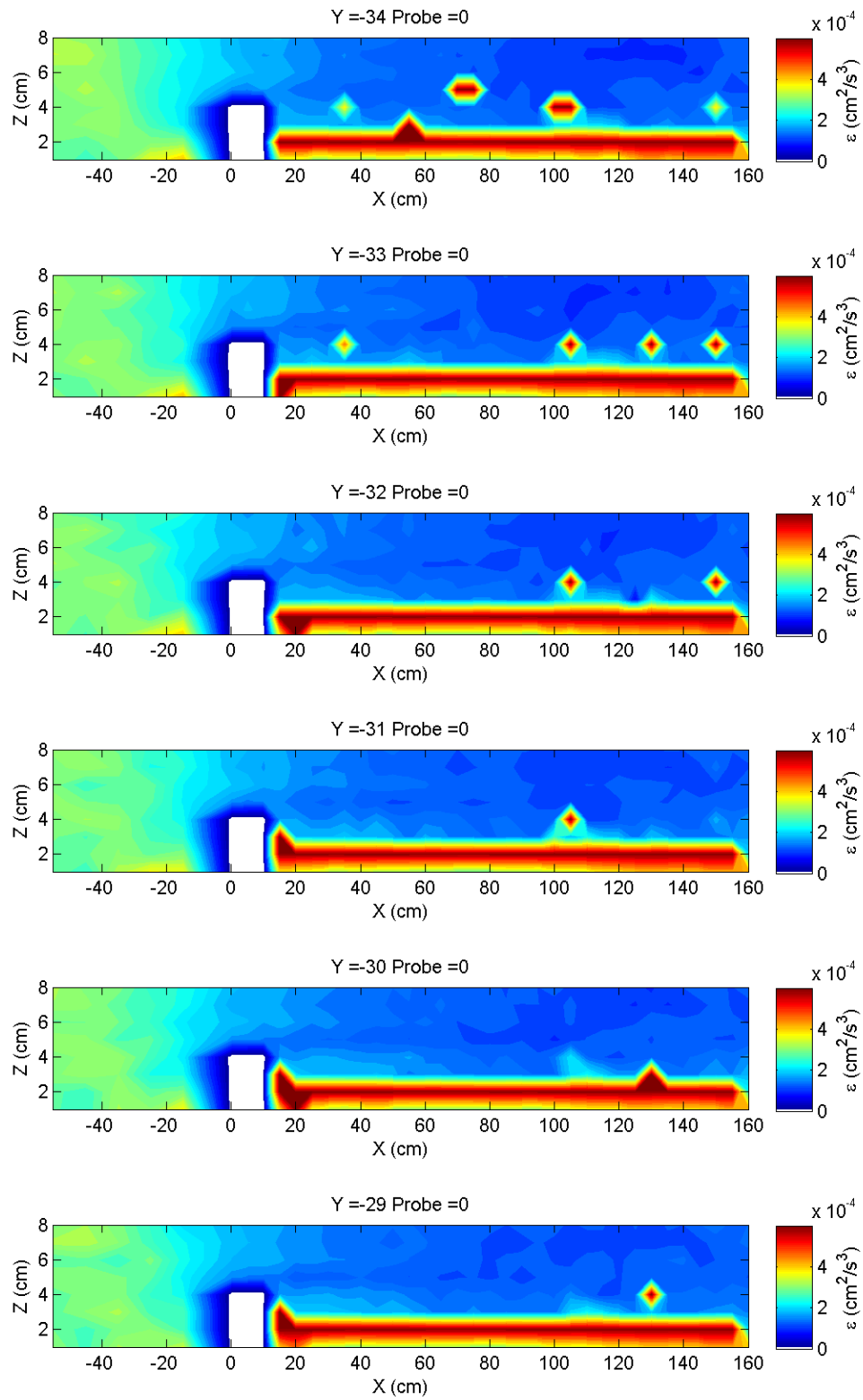


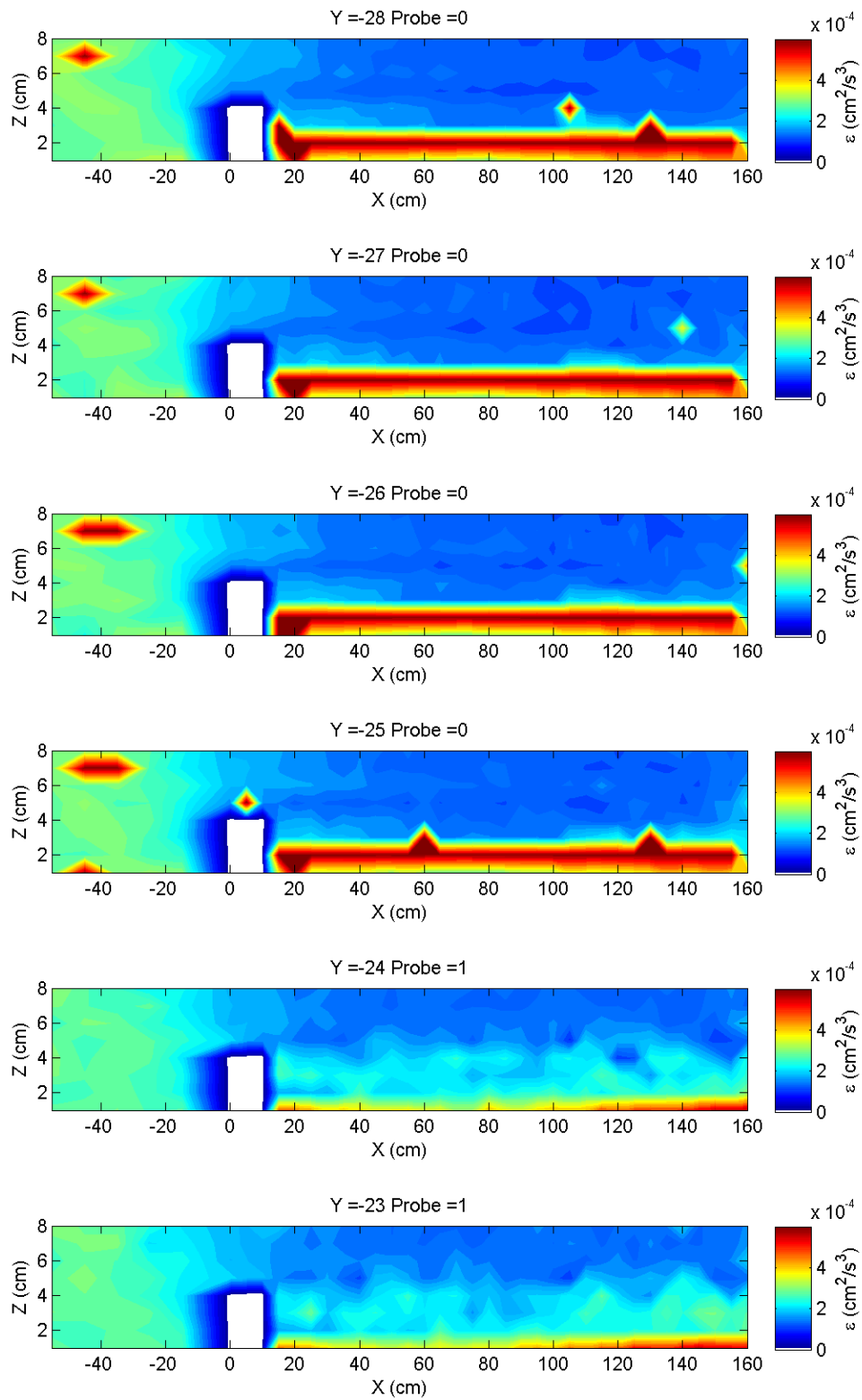


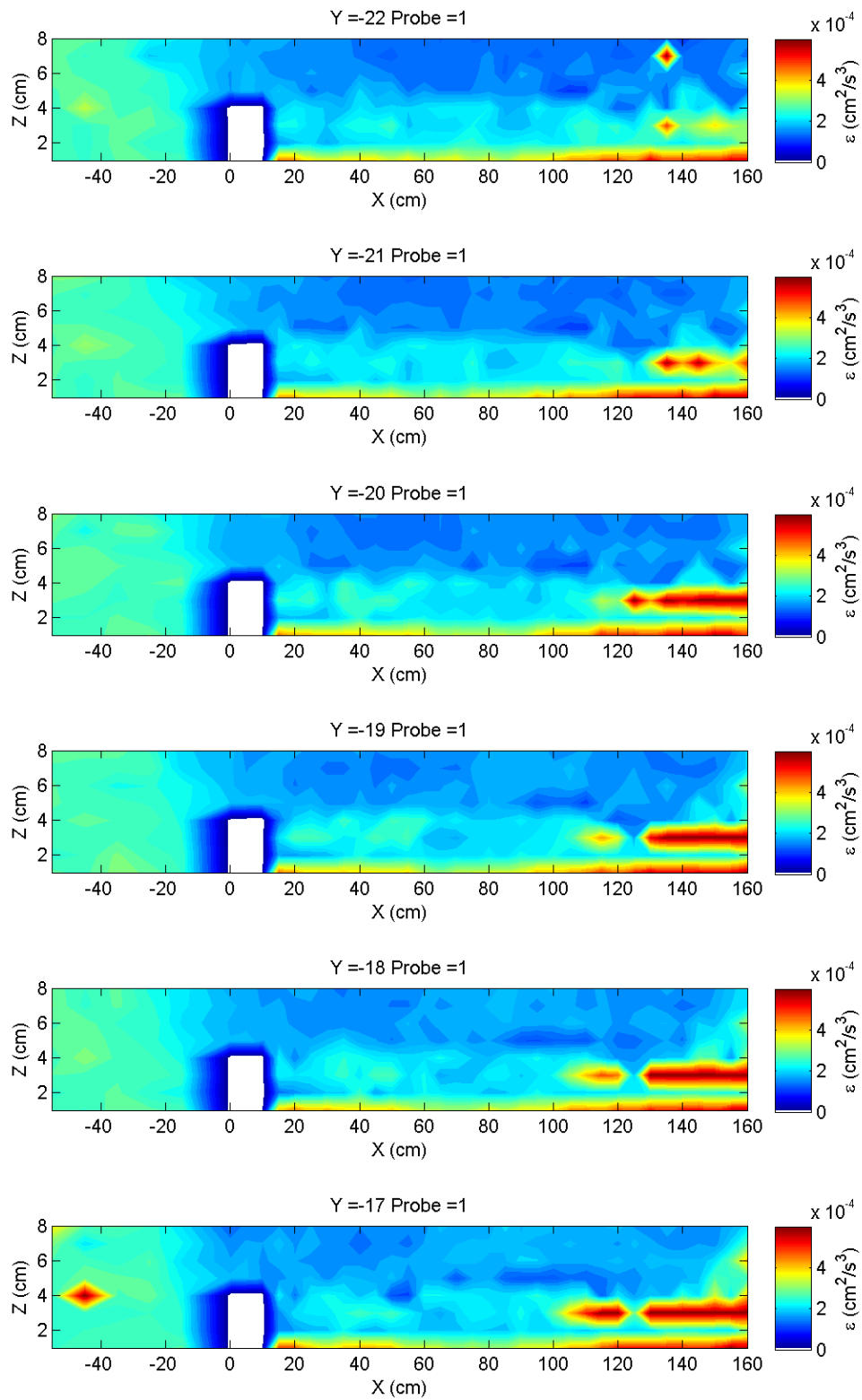


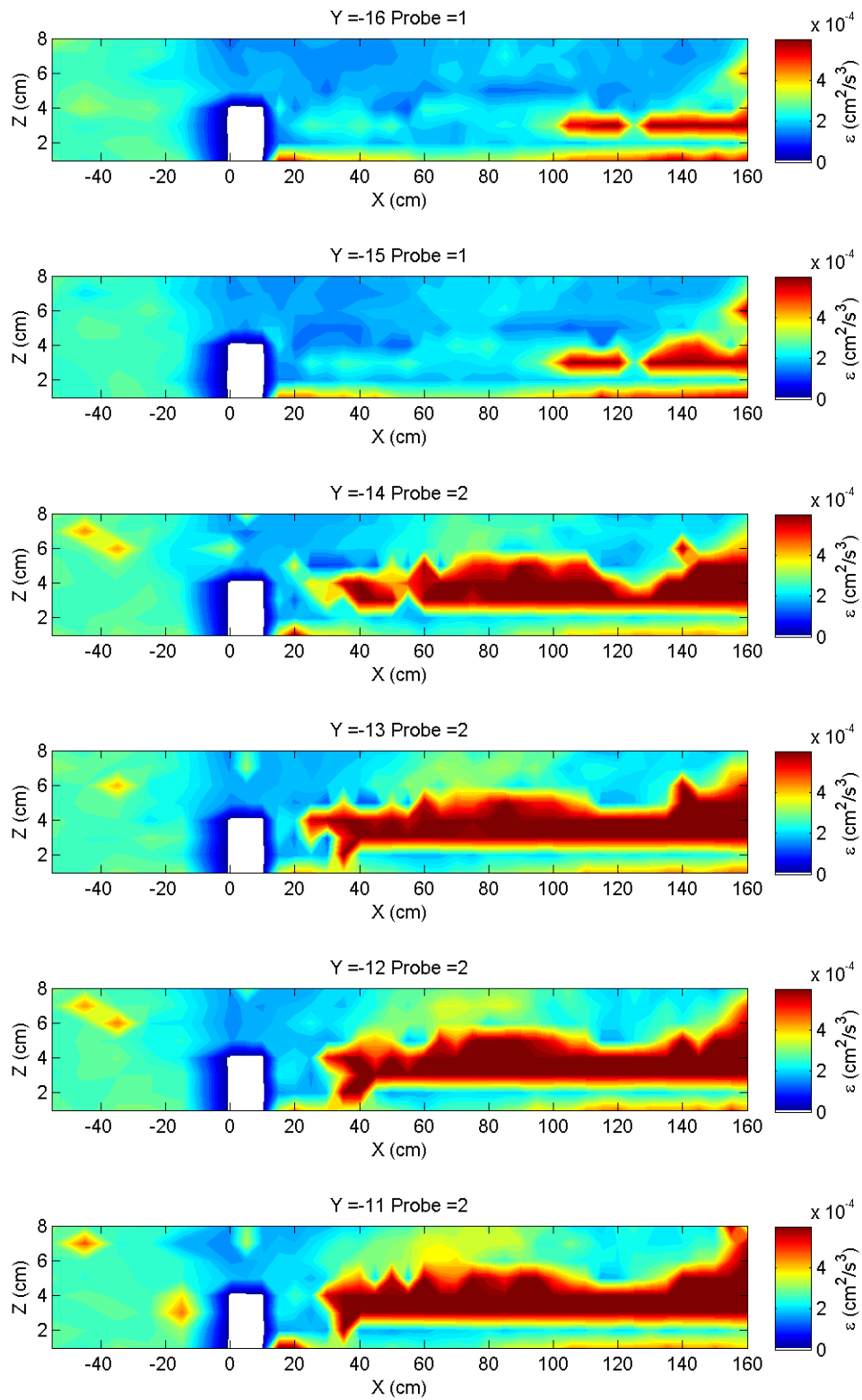


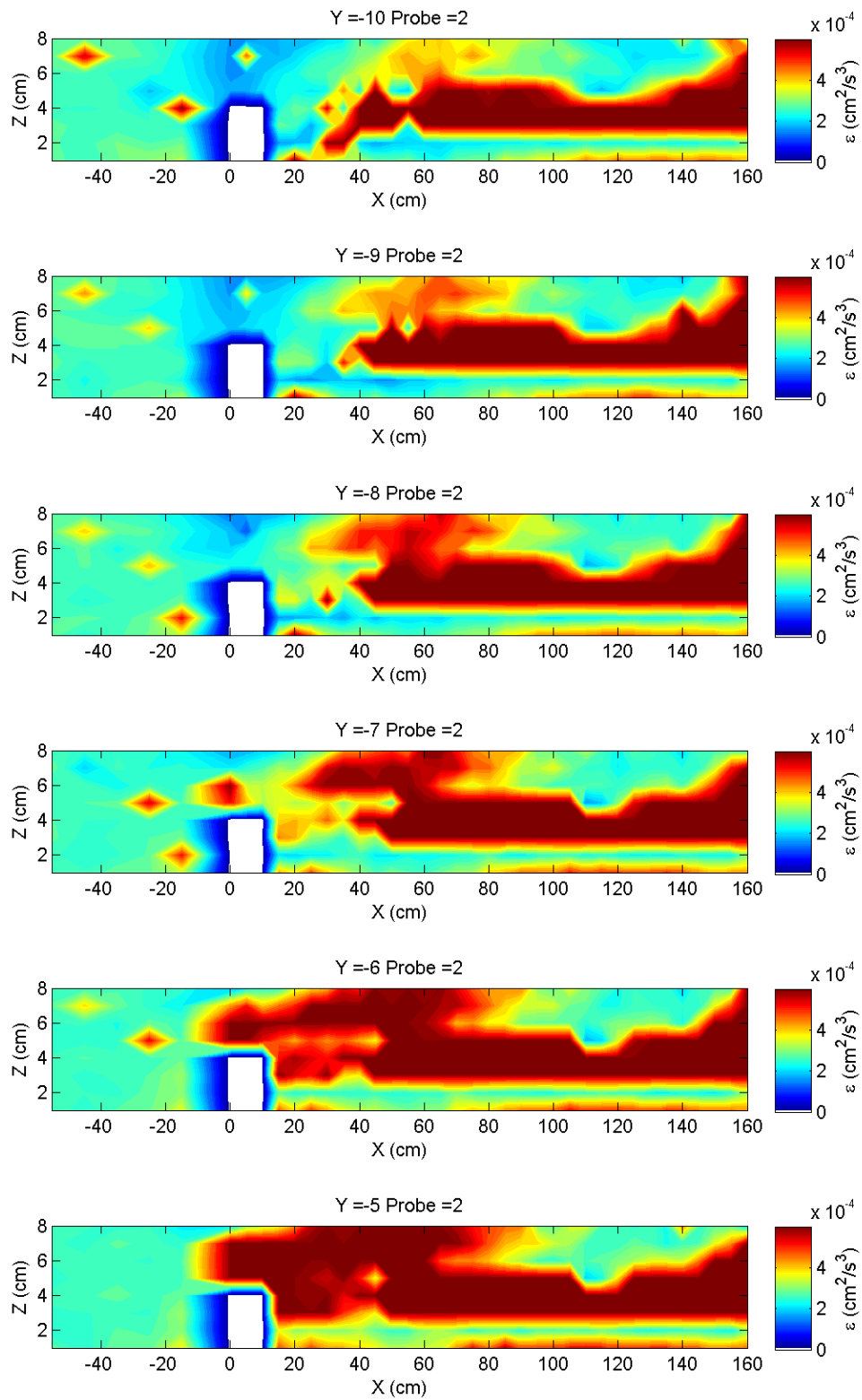
## Turbulent Dissipation Energy $\varepsilon$ in x and z-Directions



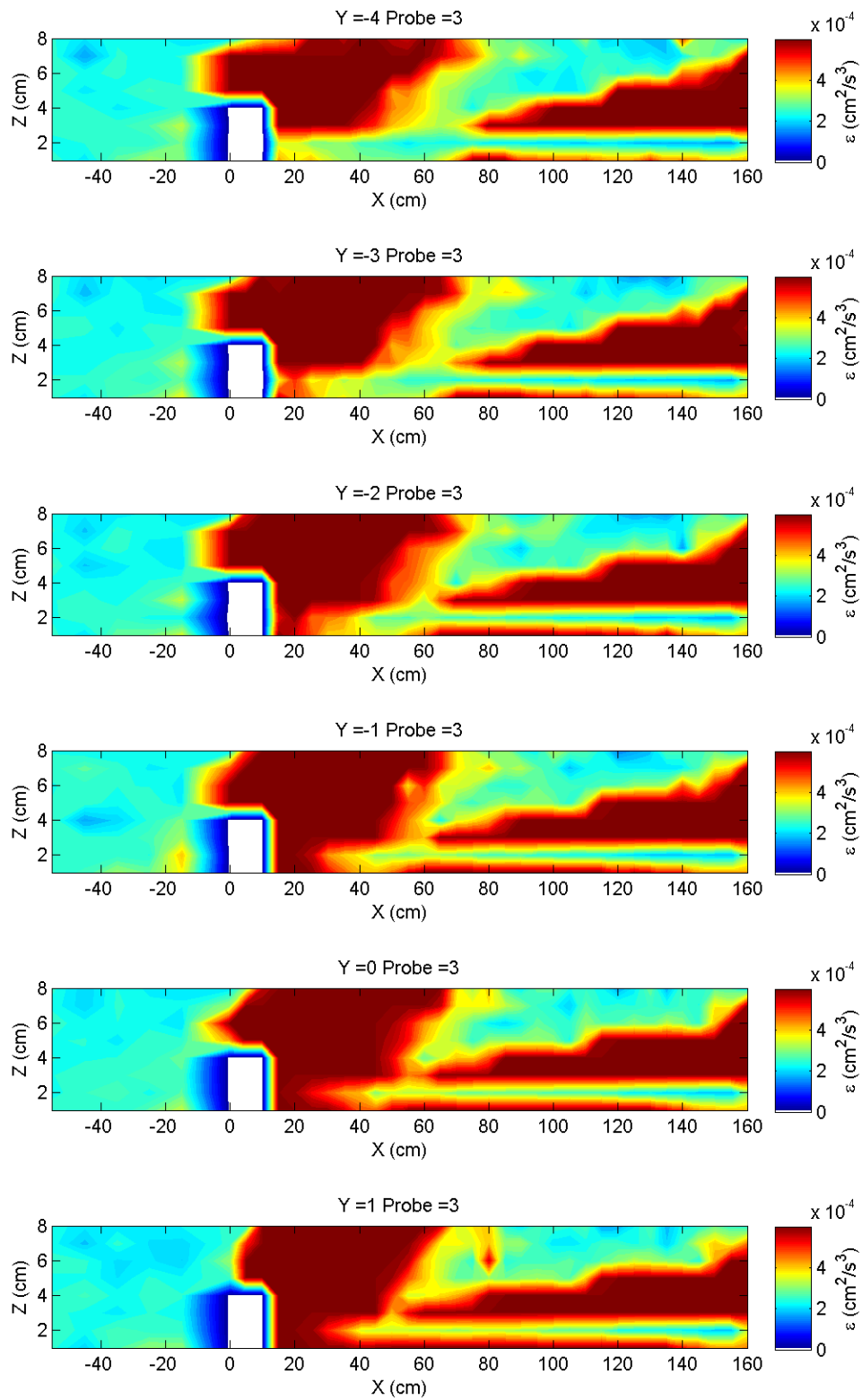


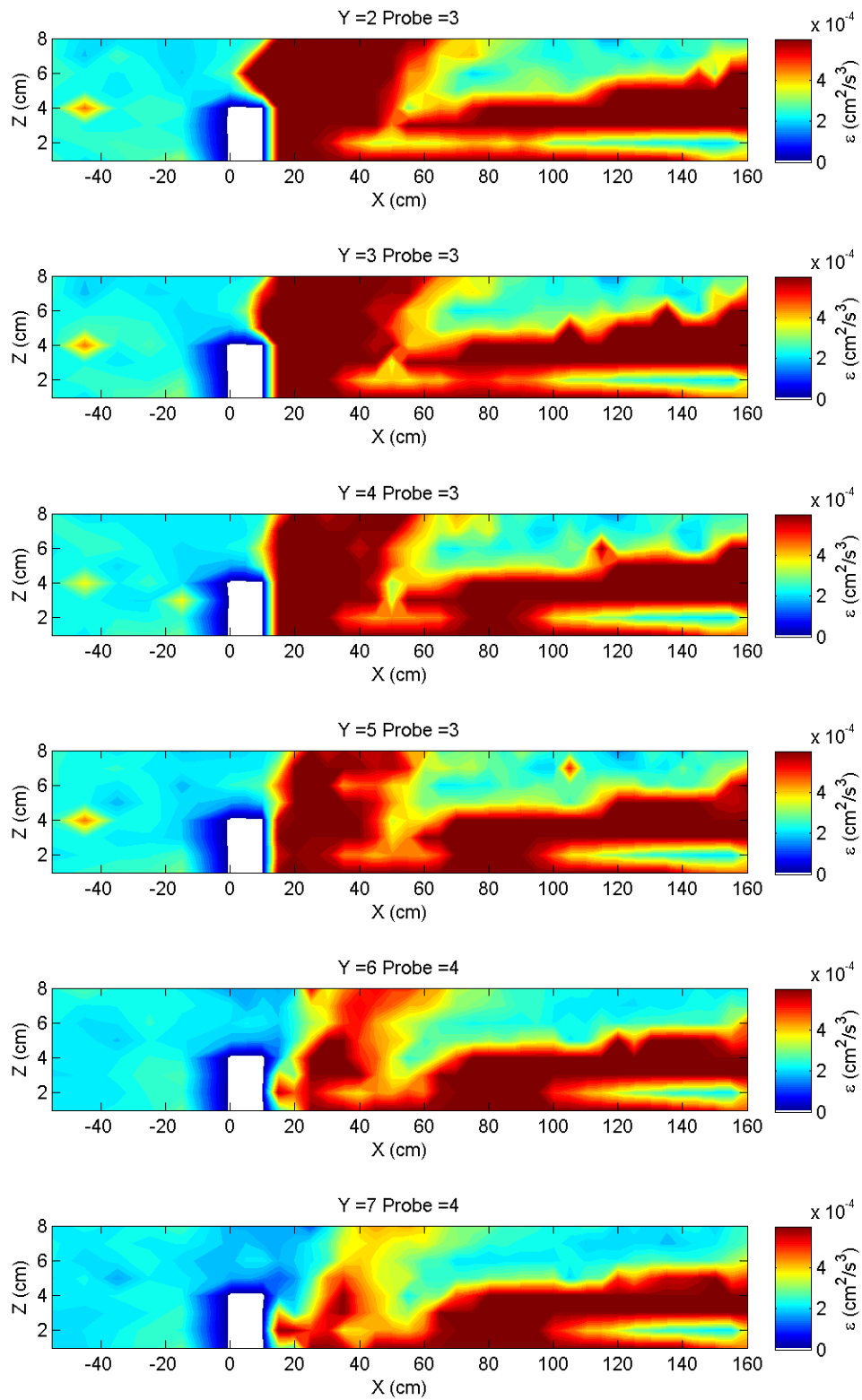


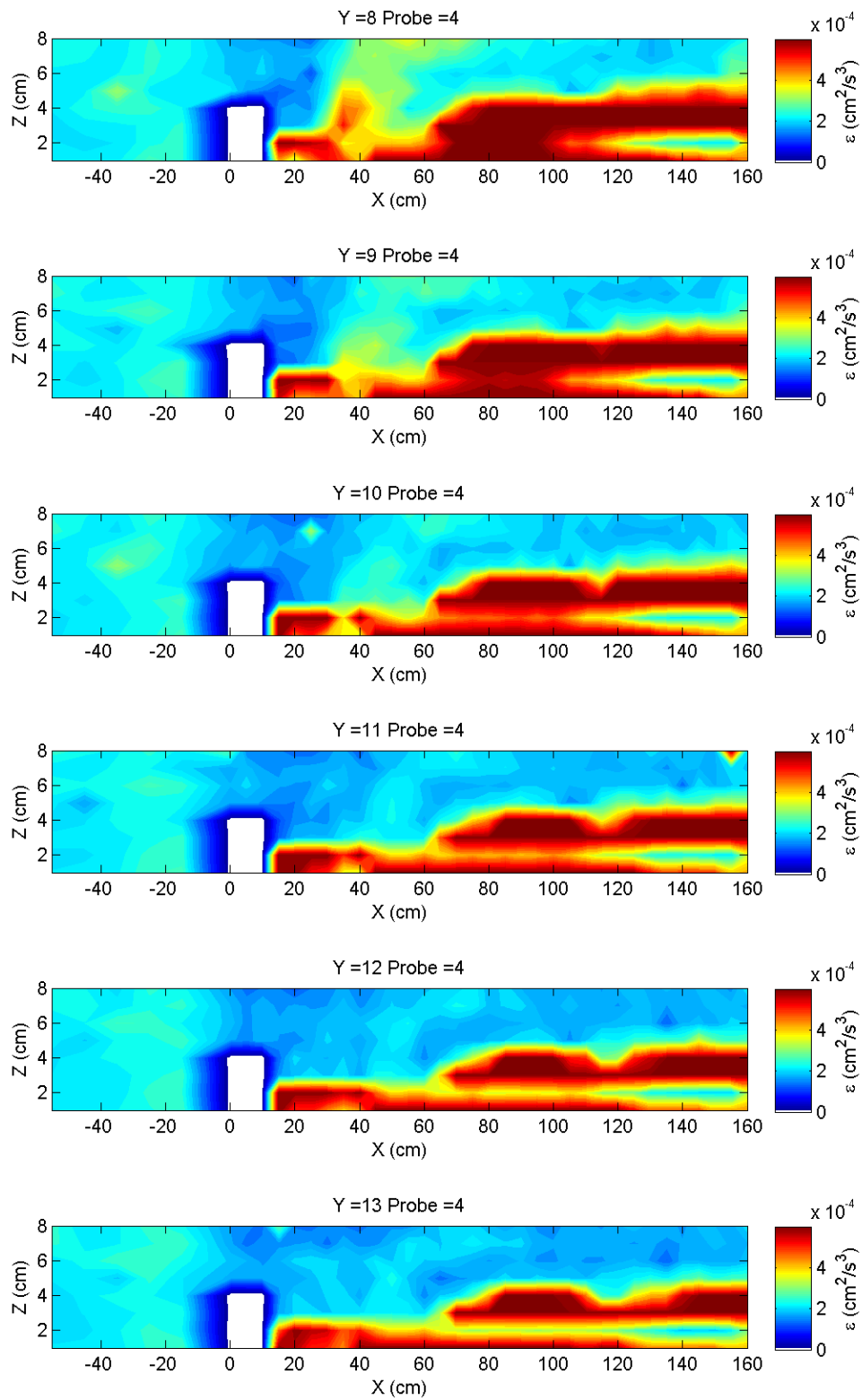


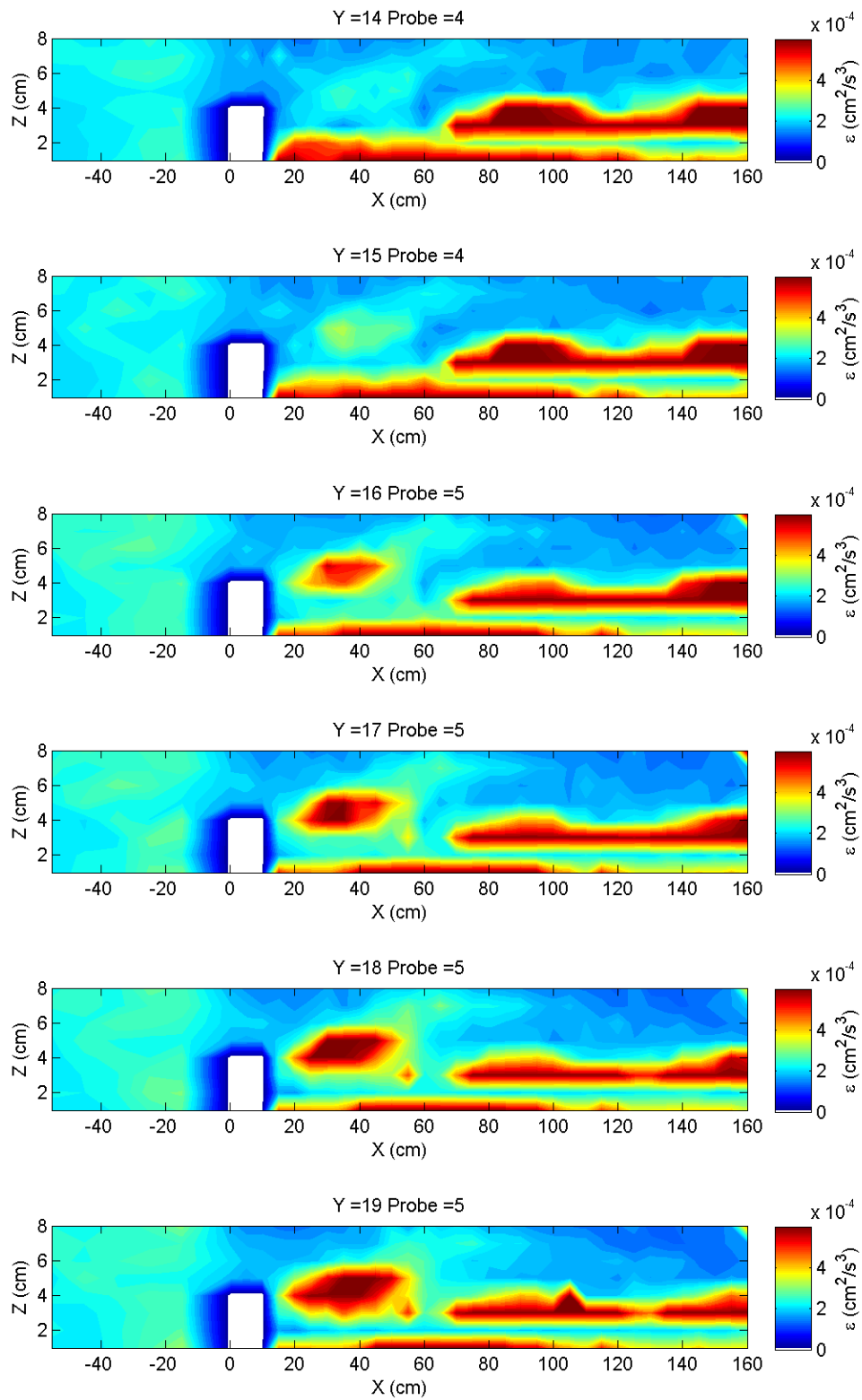


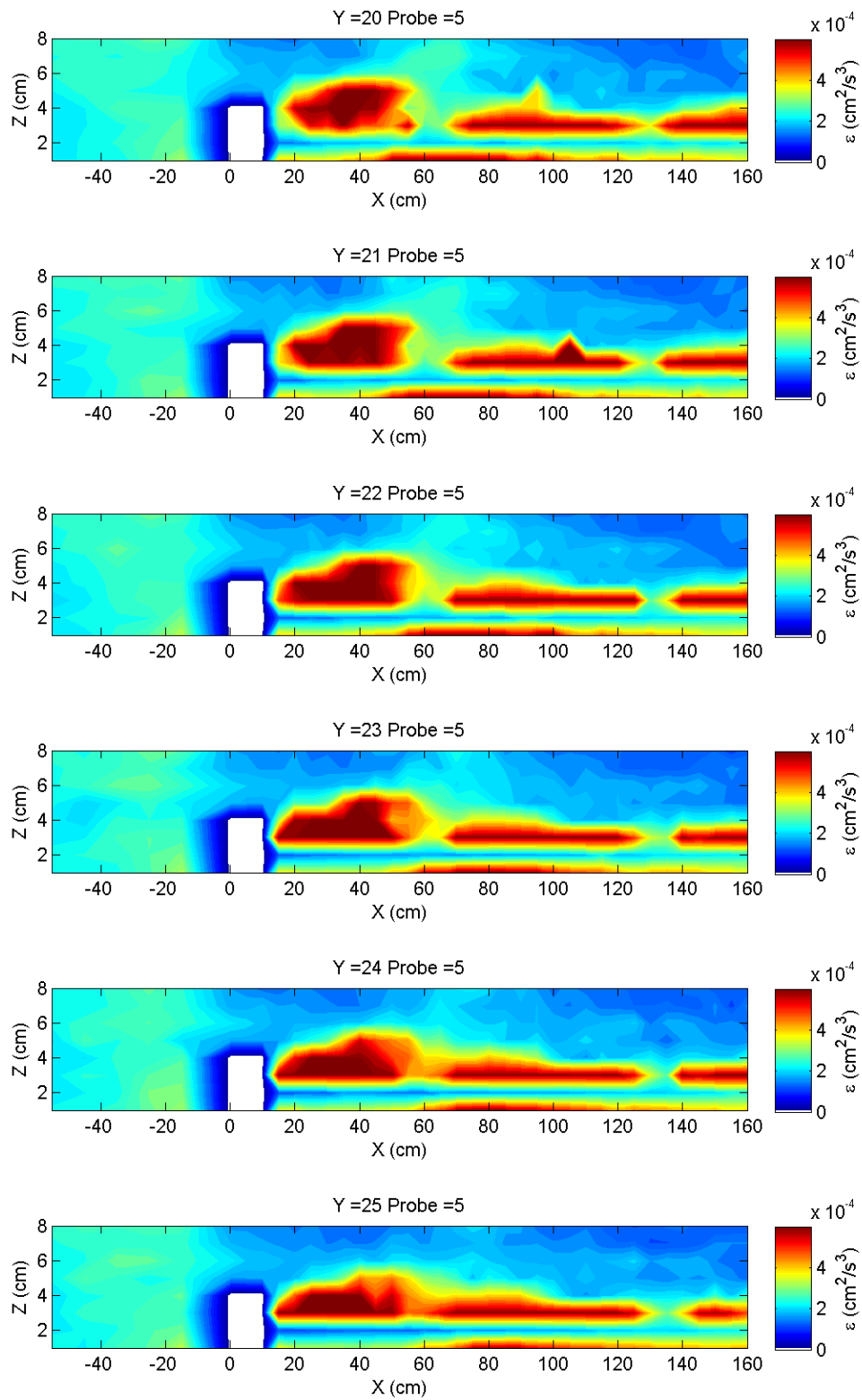


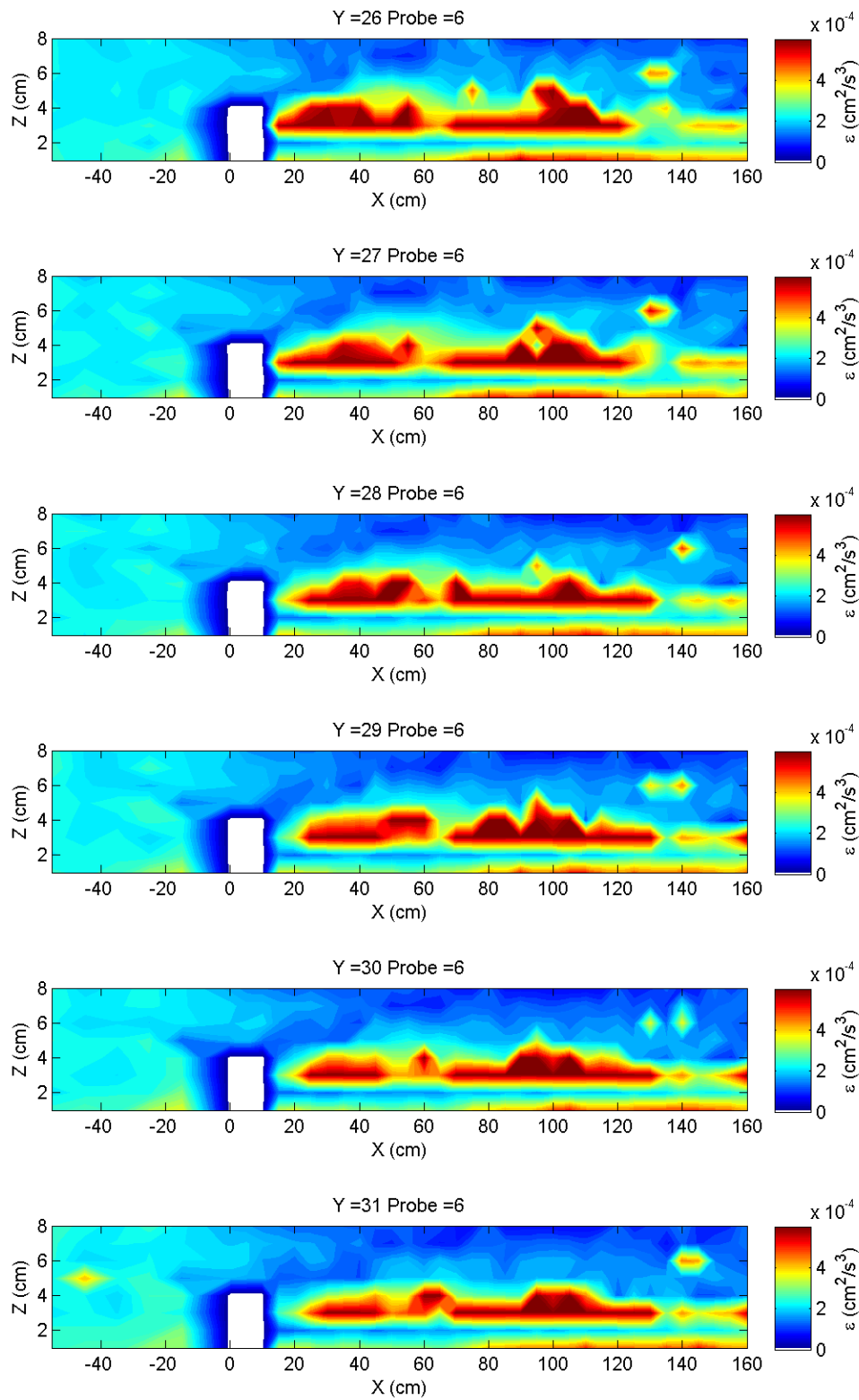


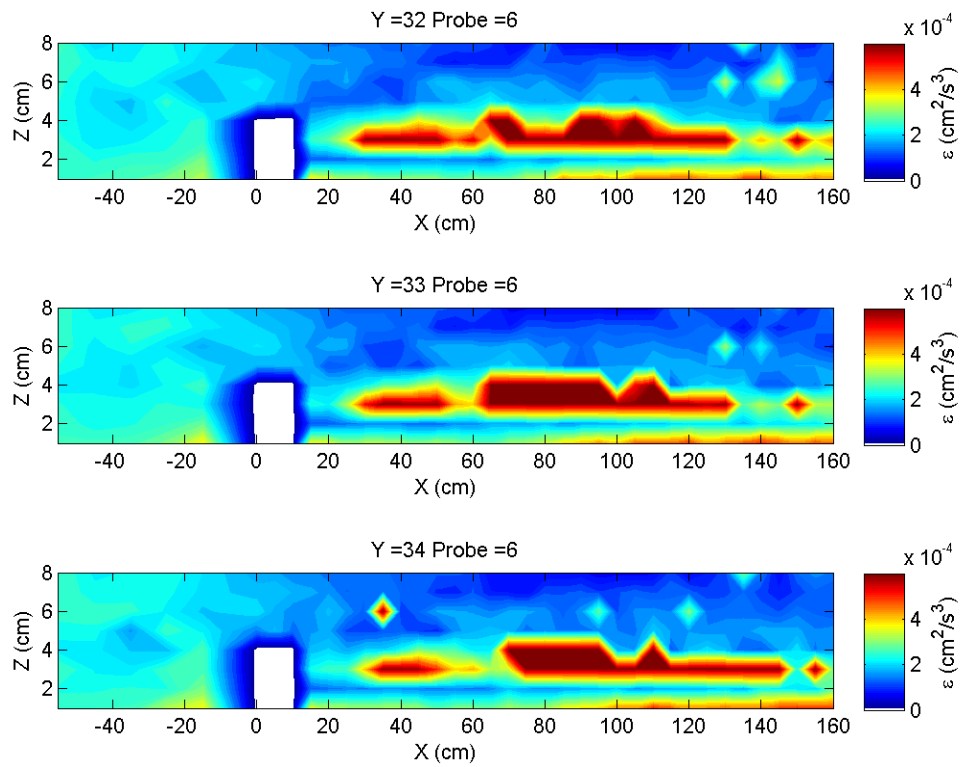








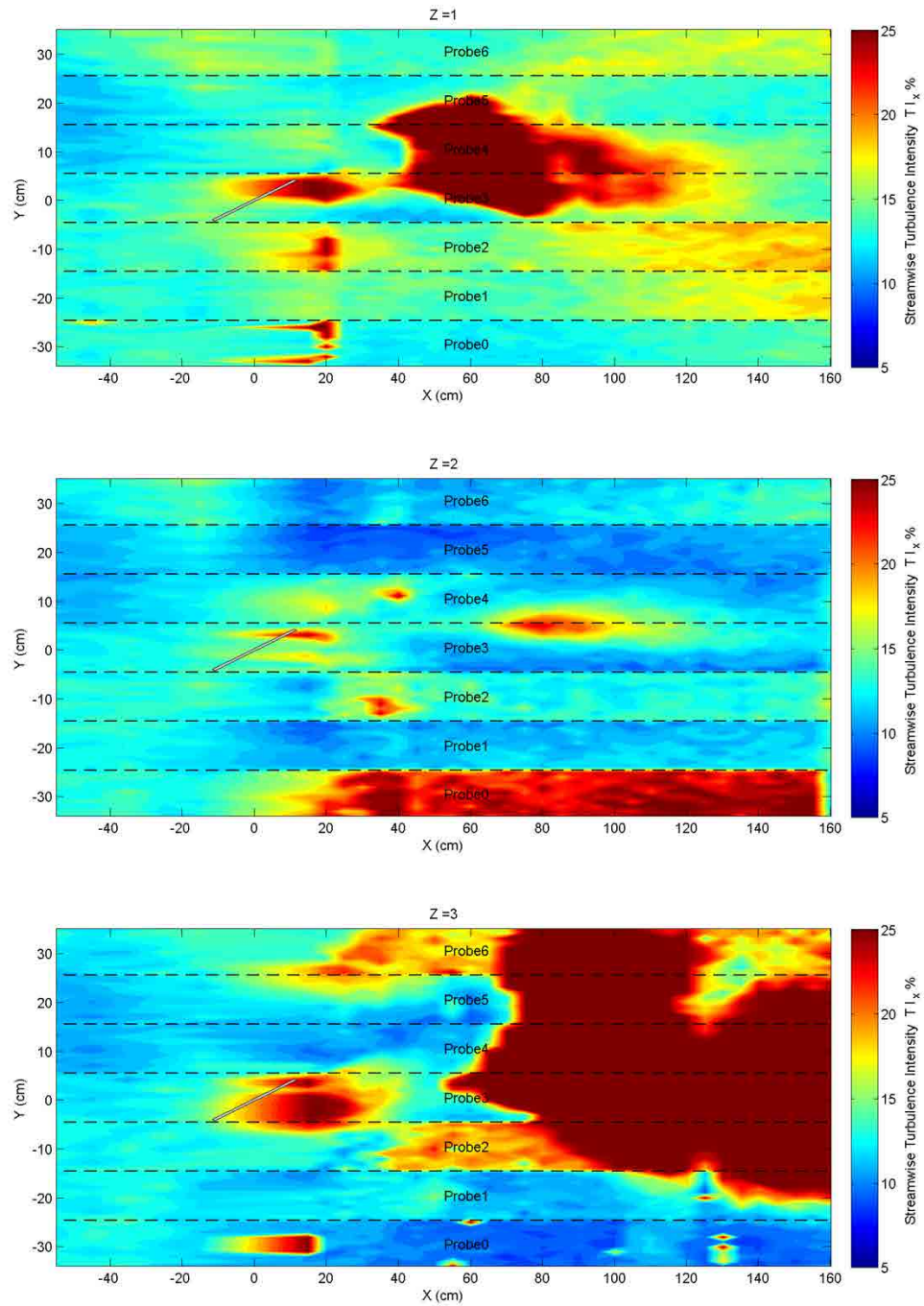




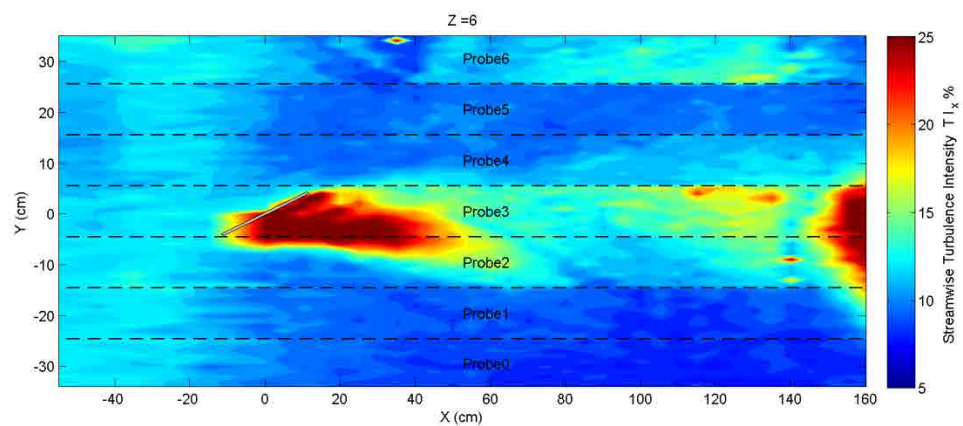
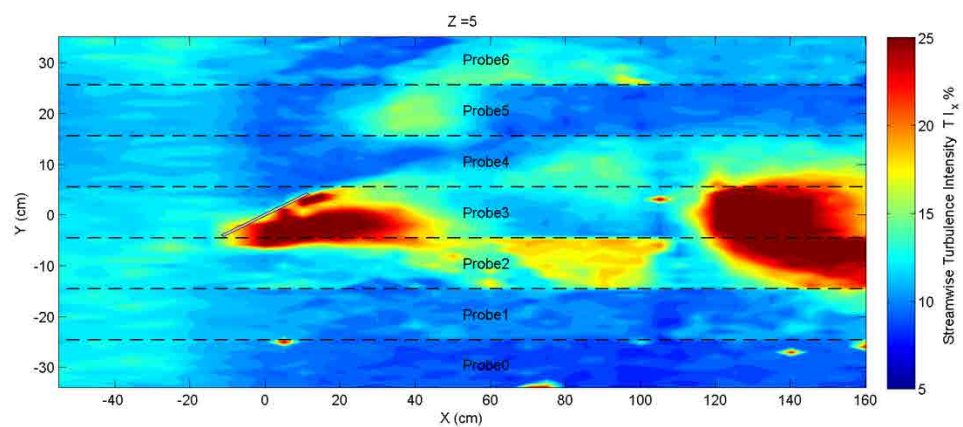
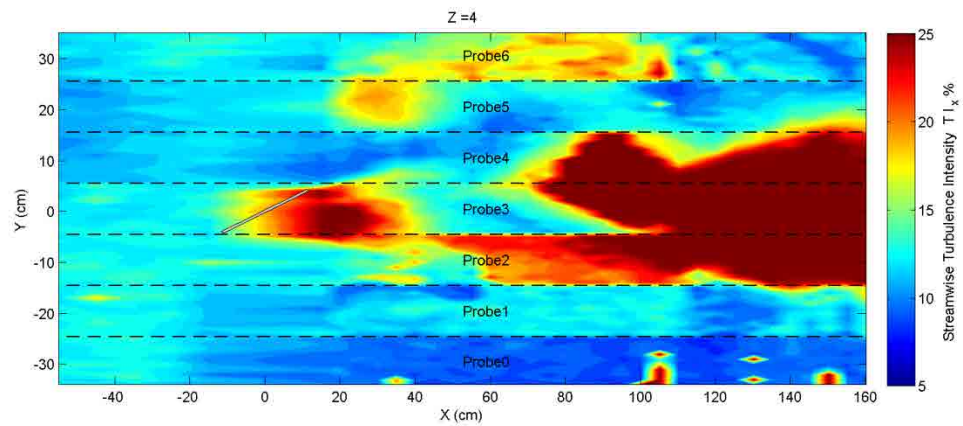
## Appendix C Results – Submerged Vanes Turbulence Statistics

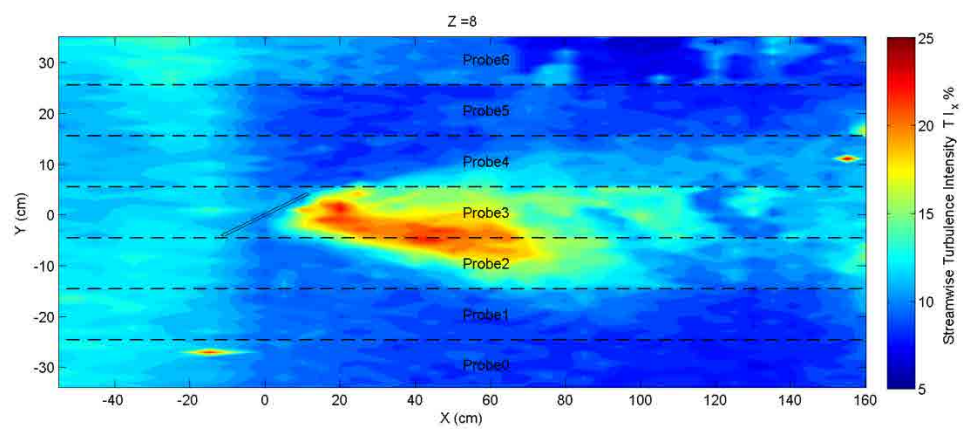
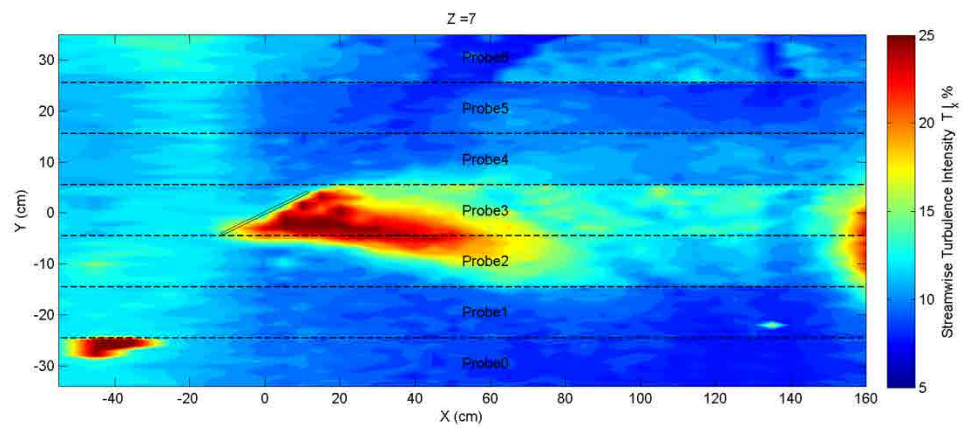
### C.4 Turbulence Intensities

#### Turbulence Intensity $T.I_x$ in x and y-Directions

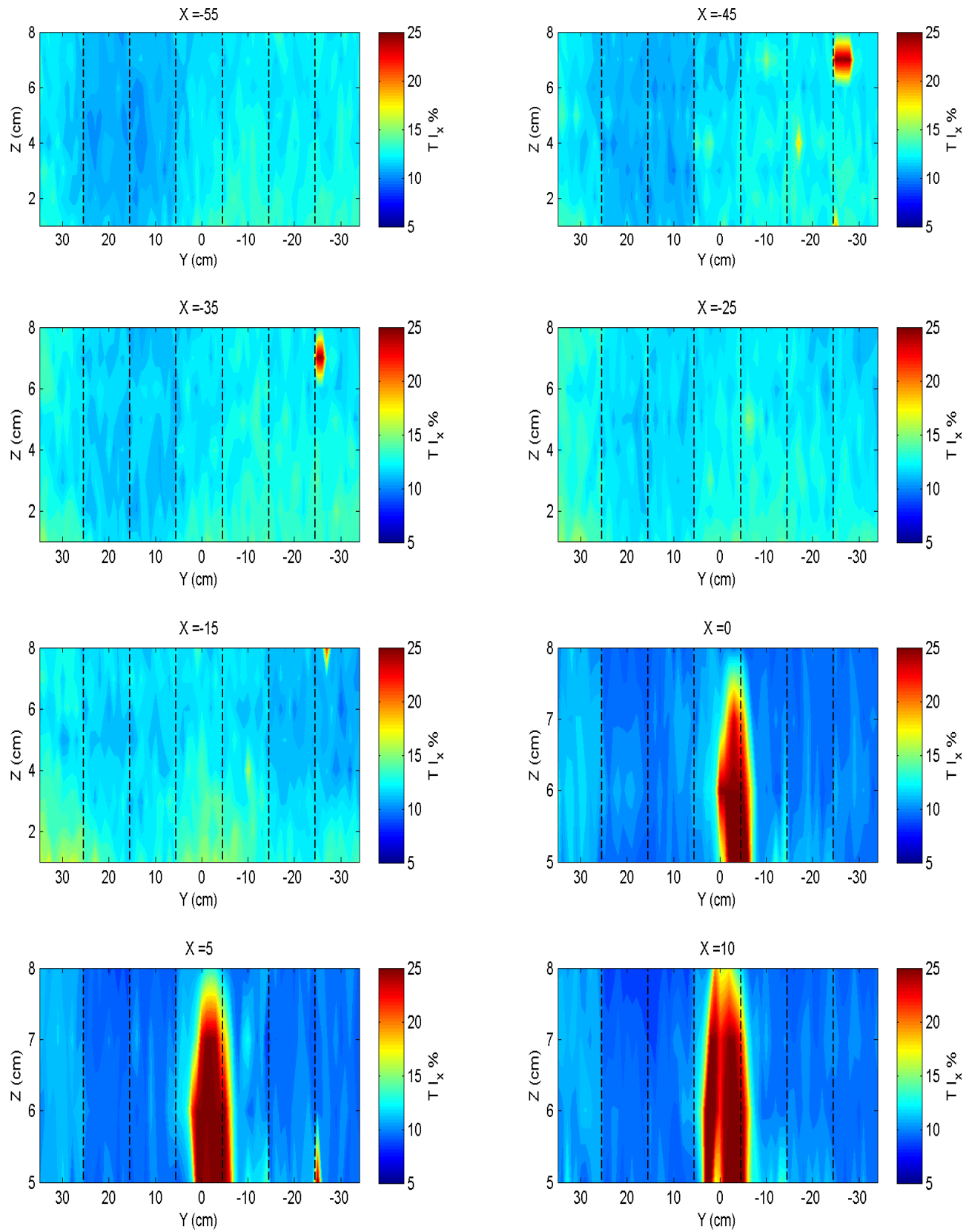


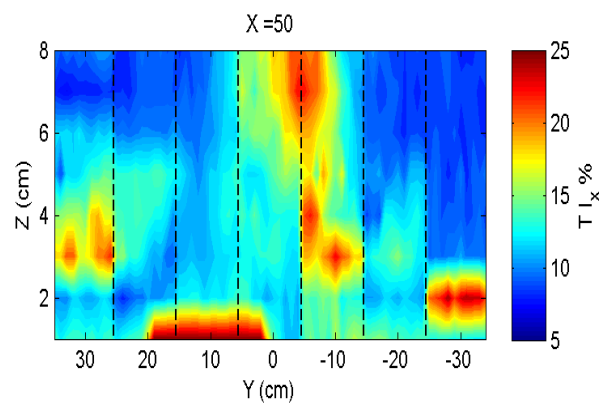
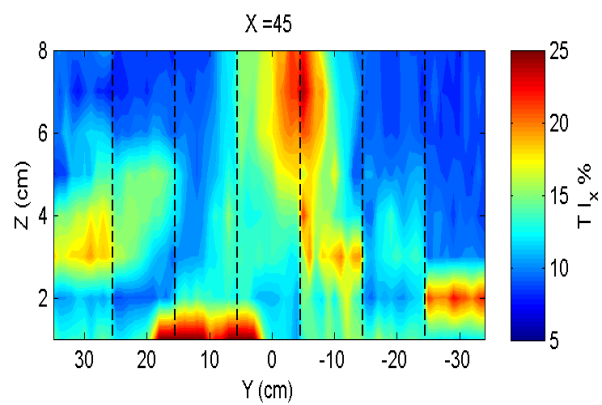
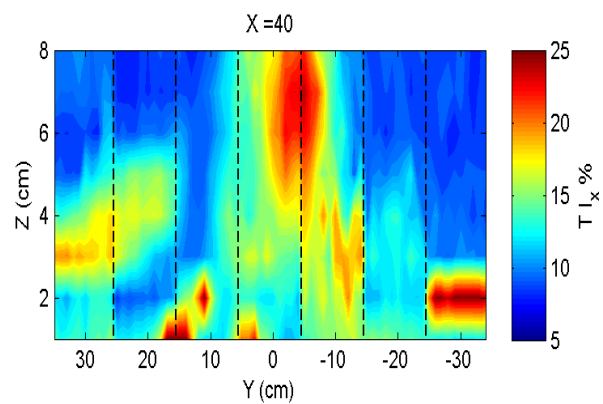
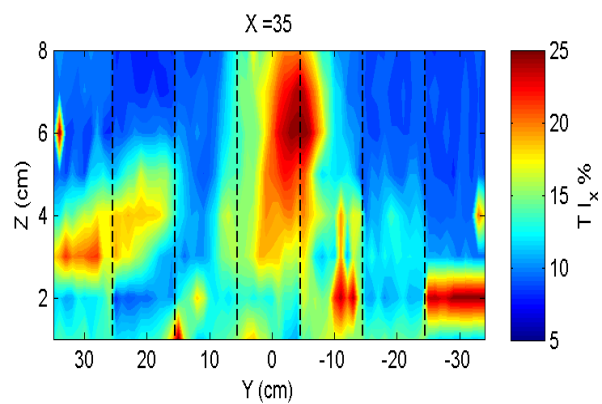
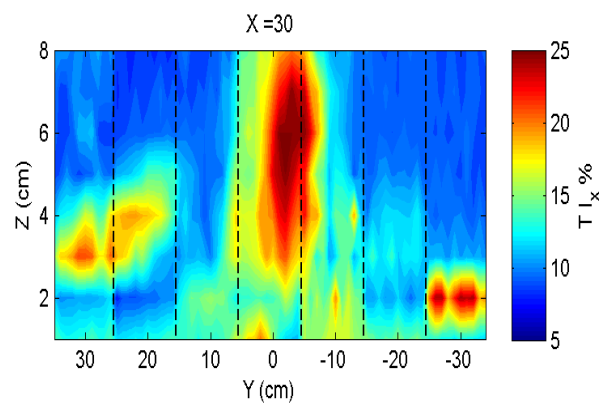
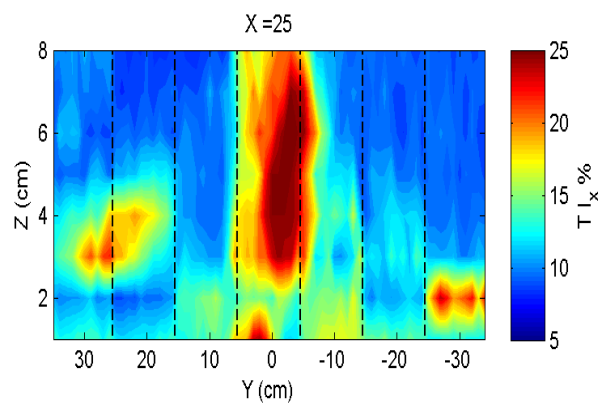
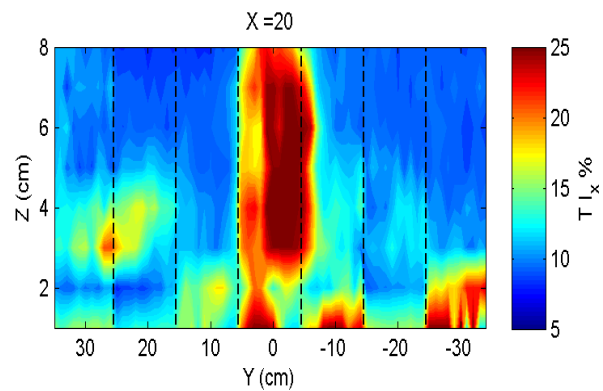
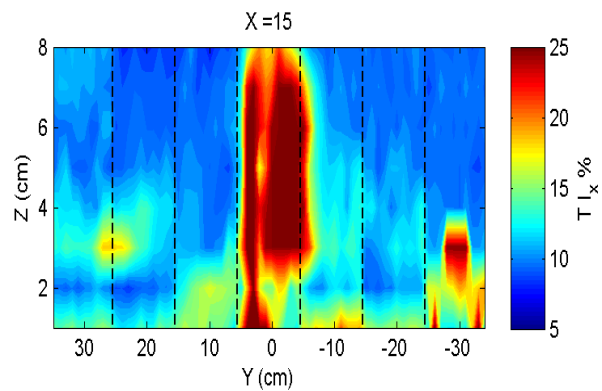


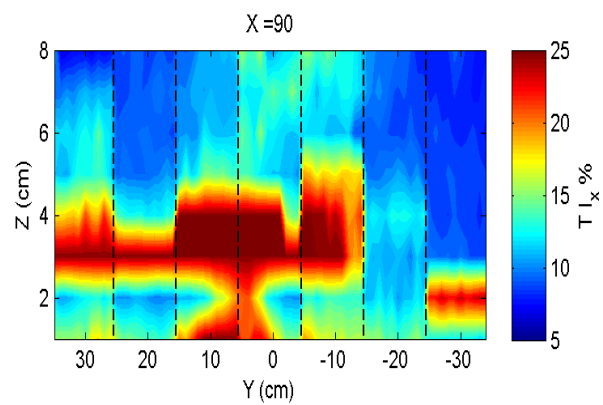
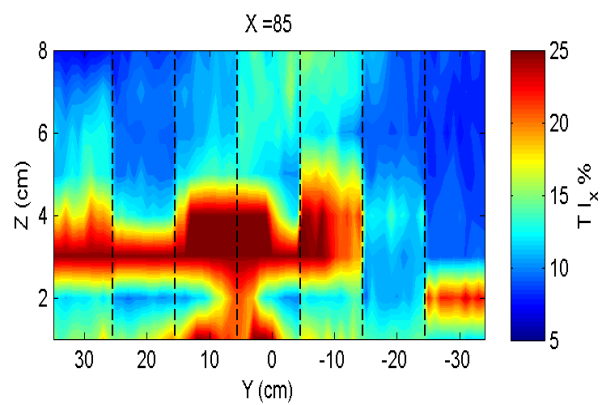
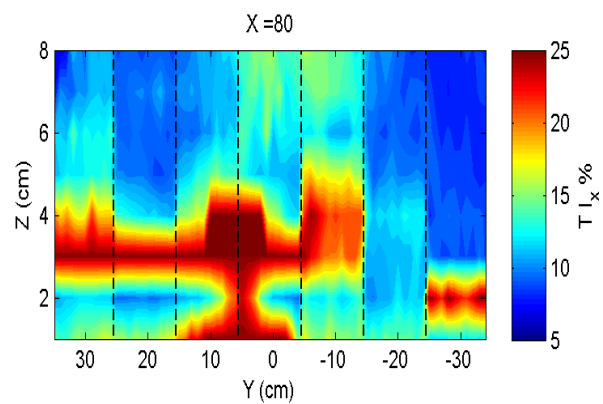
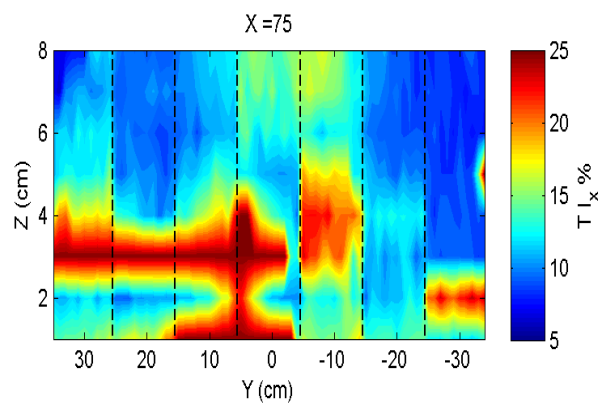
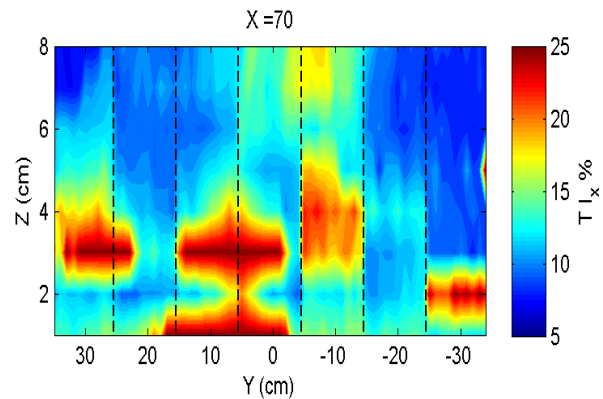
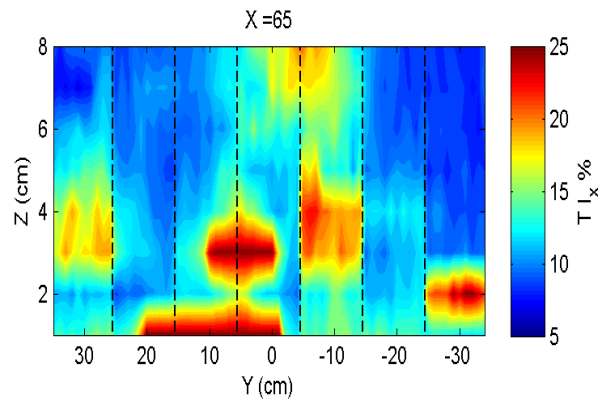
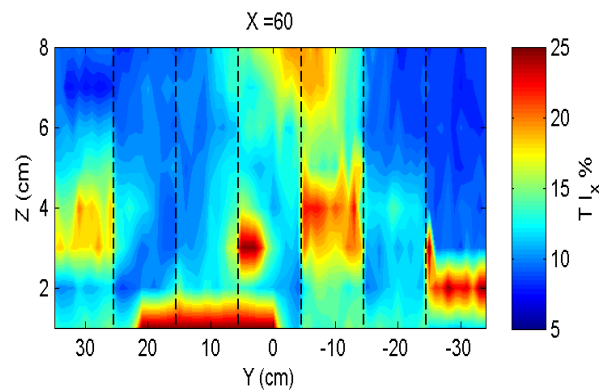
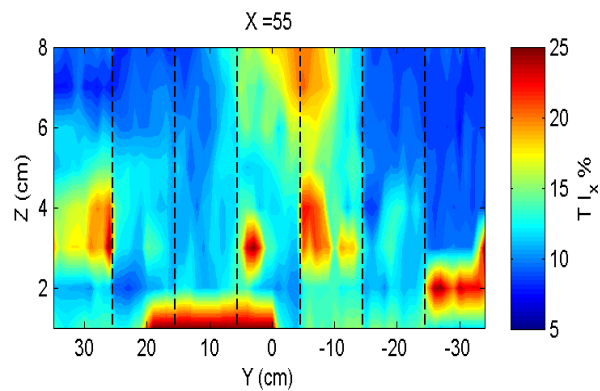




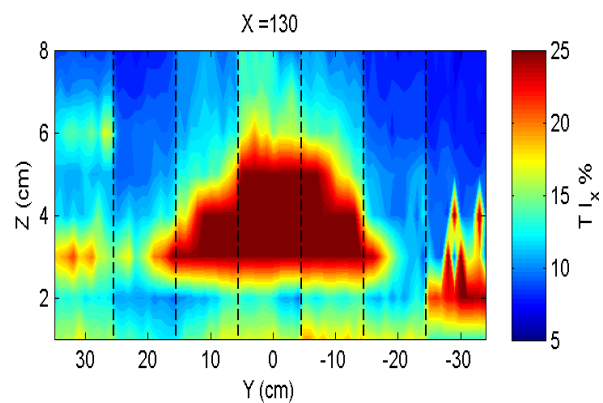
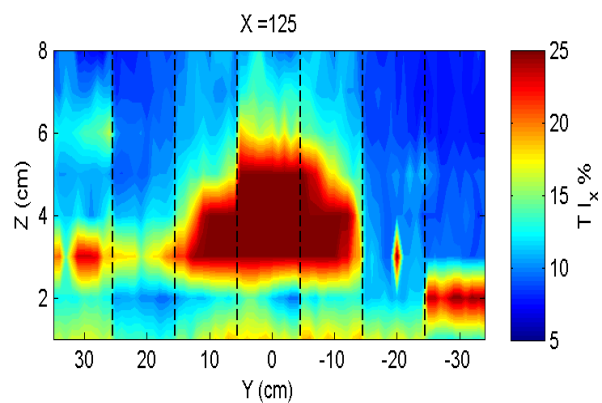
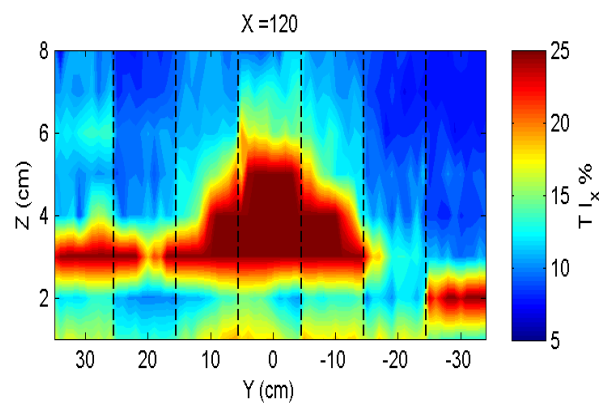
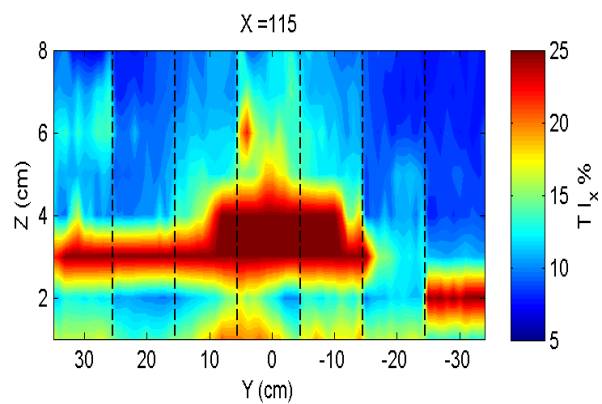
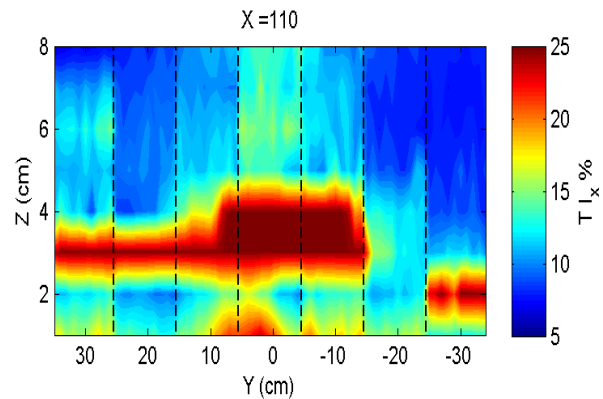
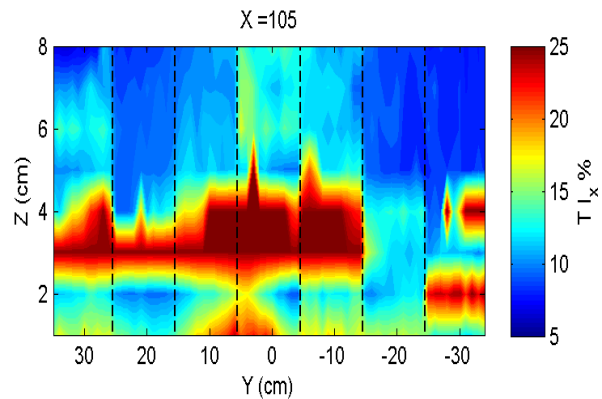
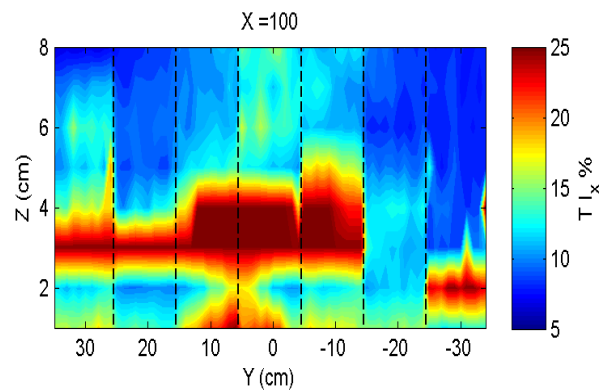
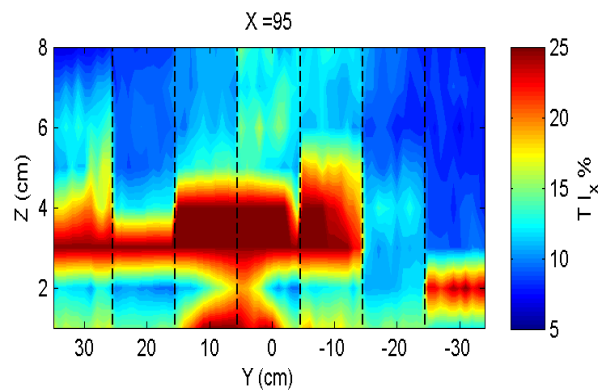
## Turbulence Intensity $T.I_x$ in y and z-Directions

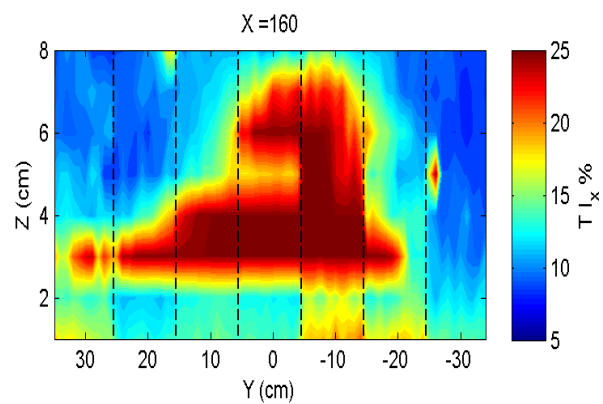
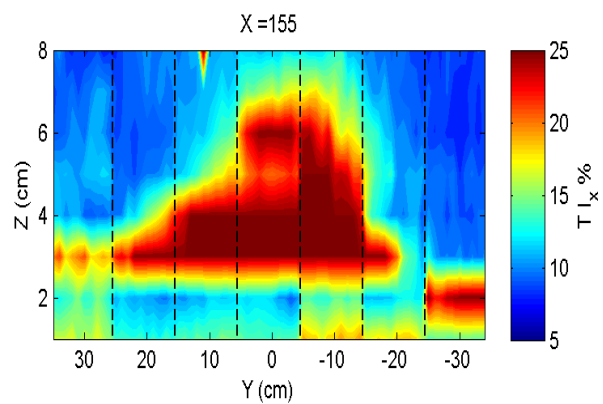
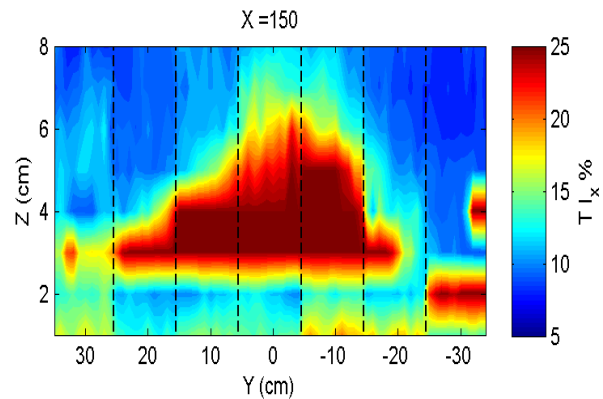
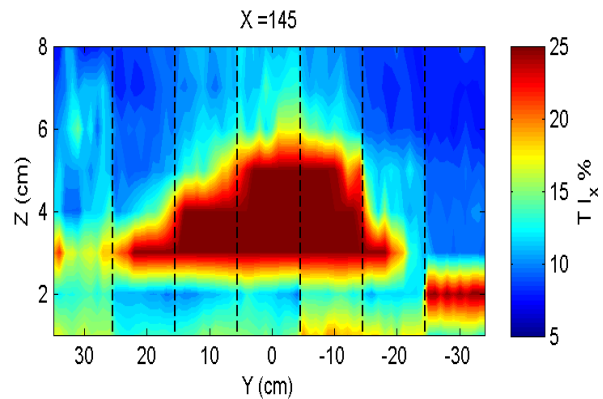
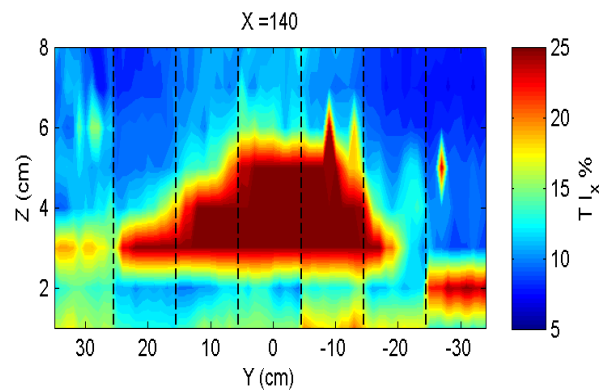
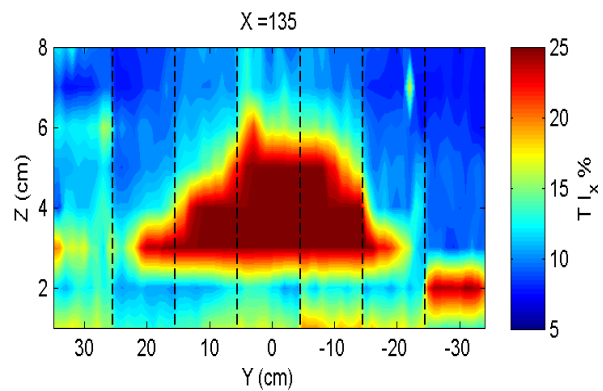




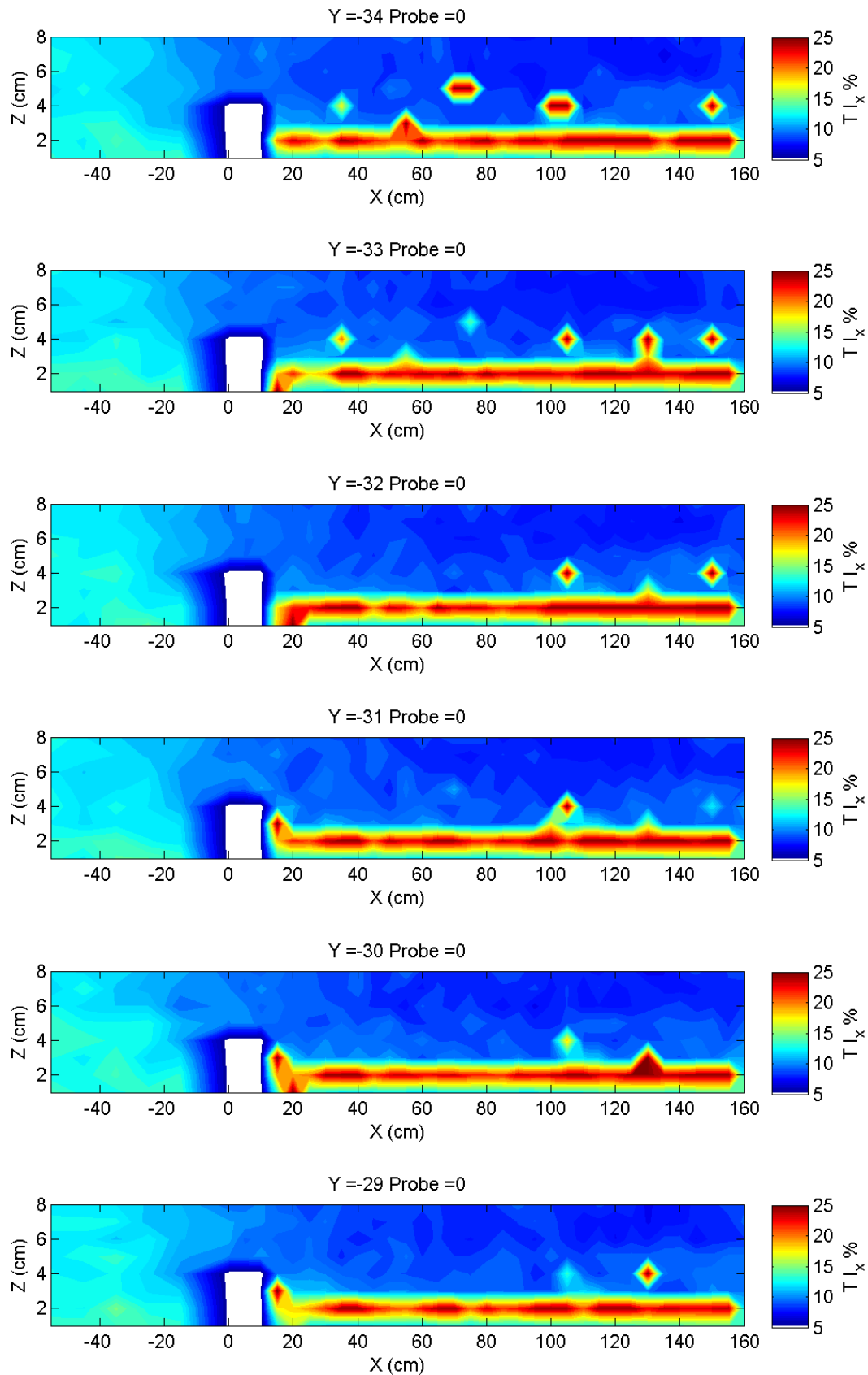




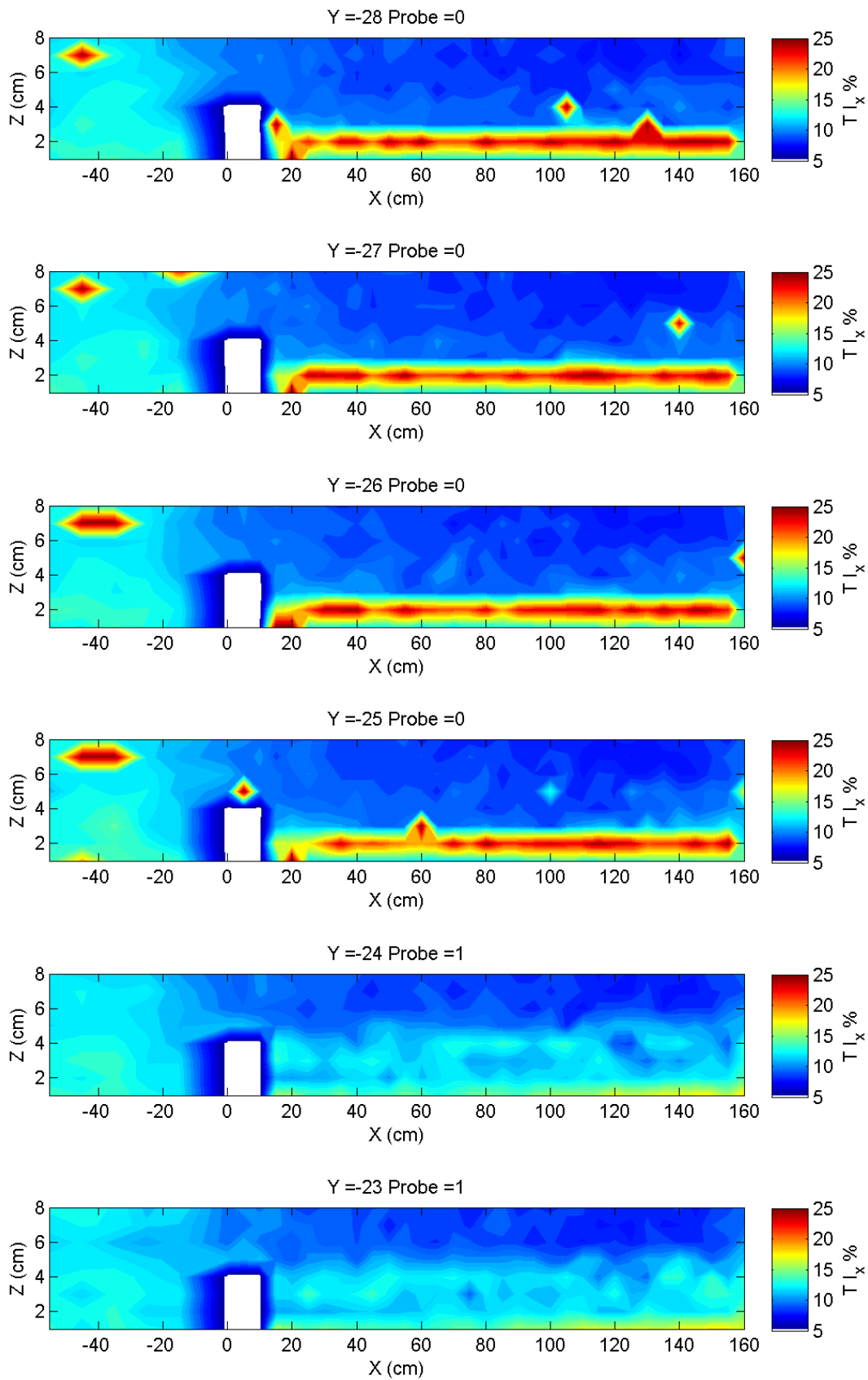


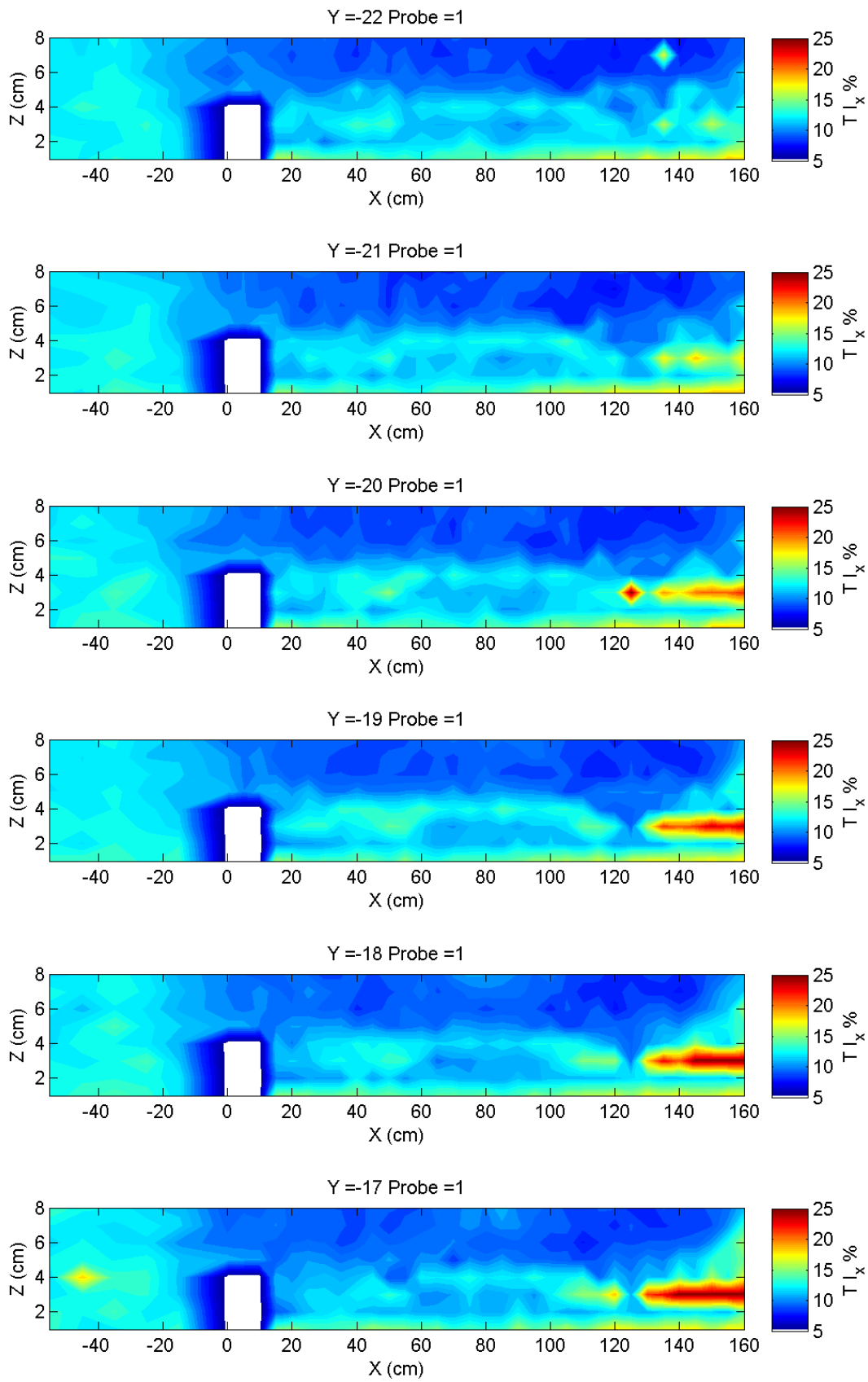


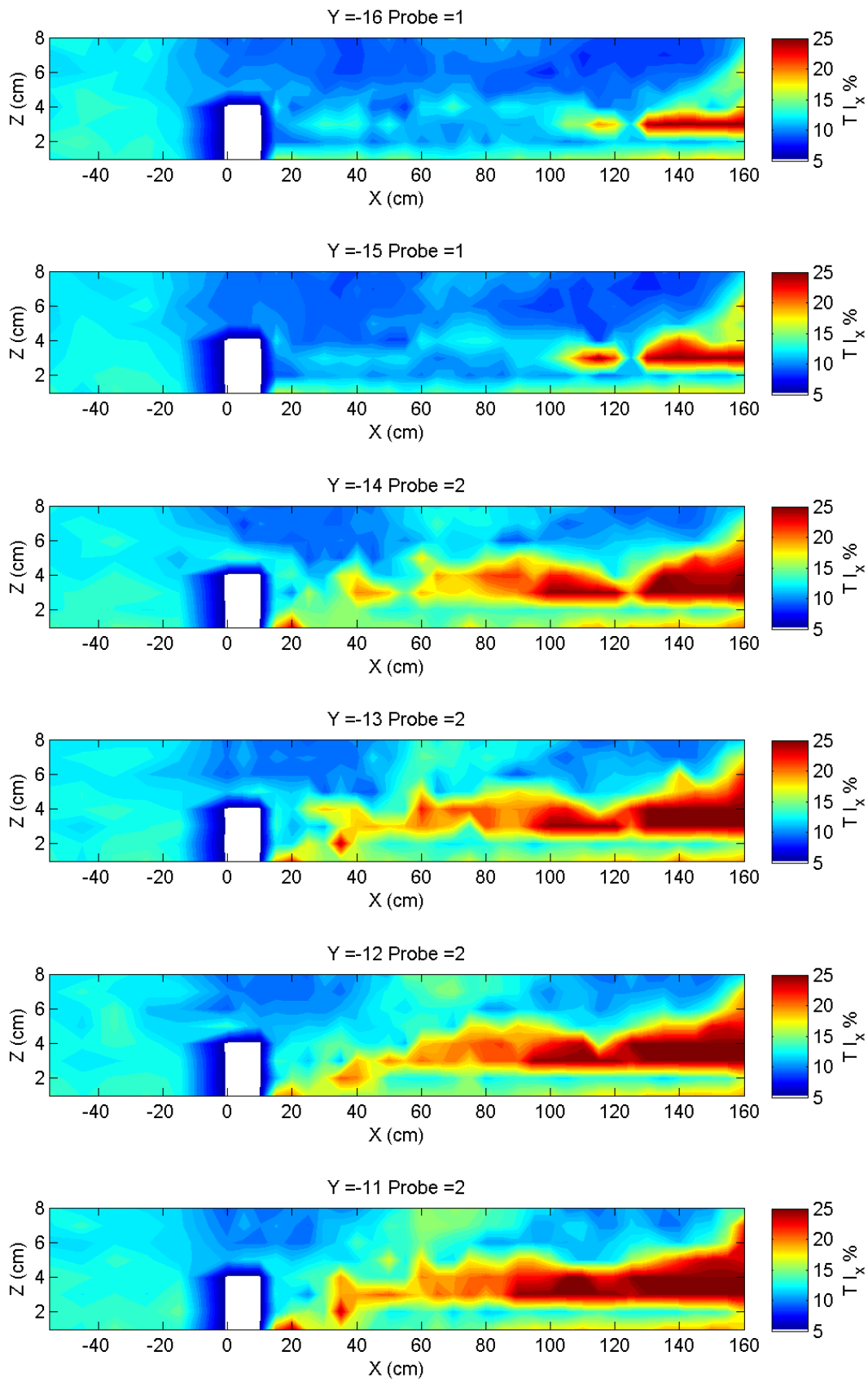
## Turbulence Intensity $T.I_x$ in x and z-Directions

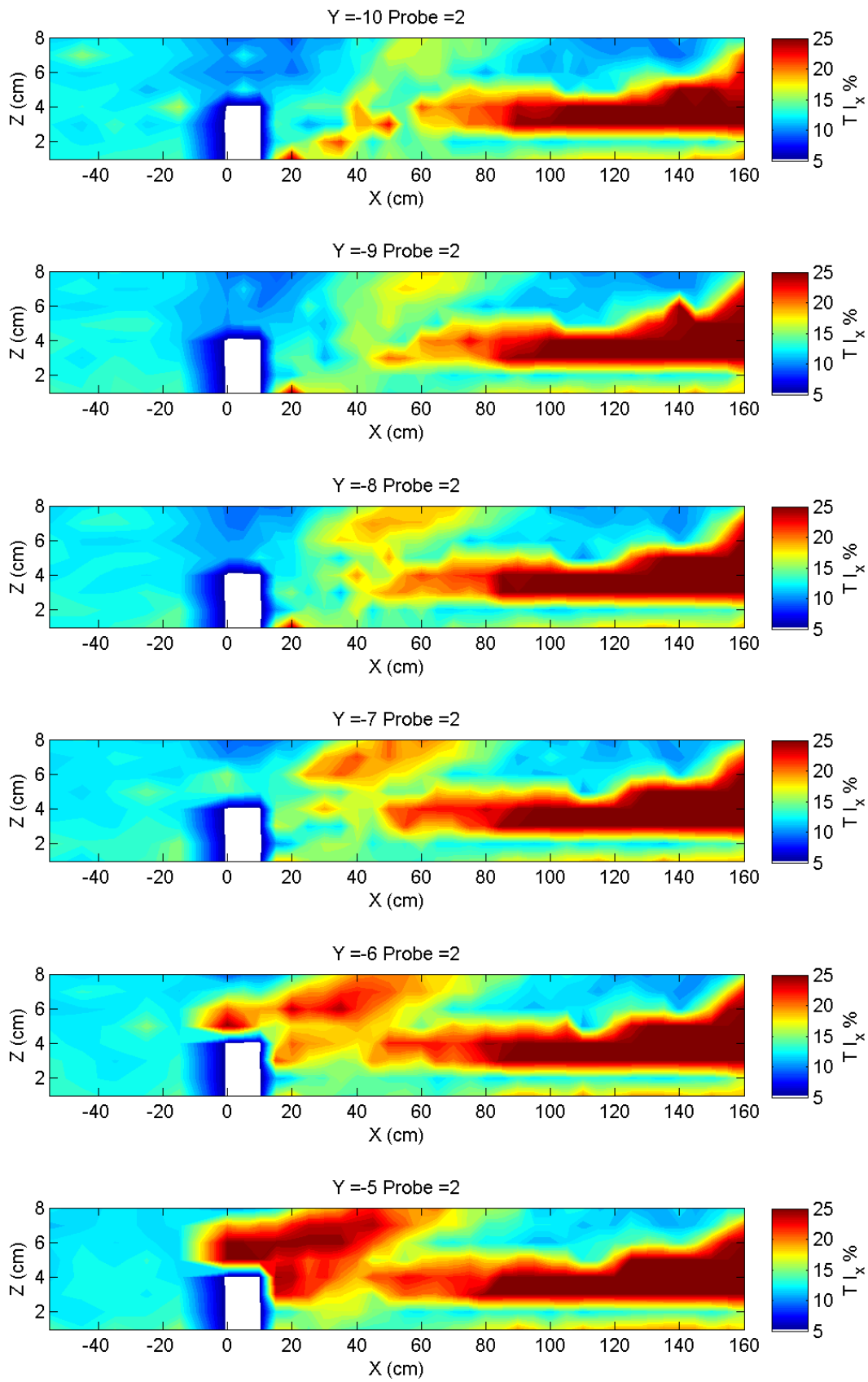


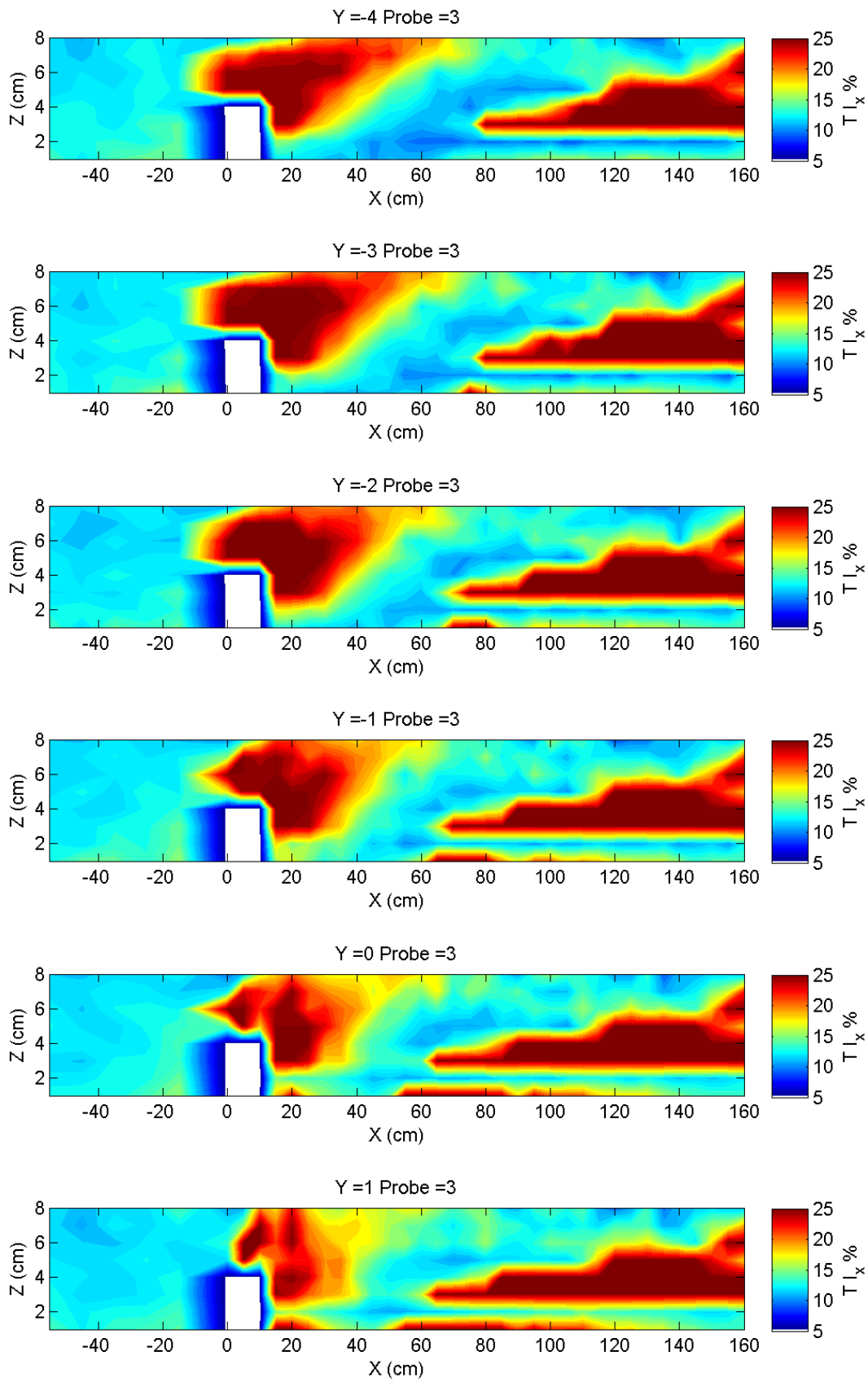


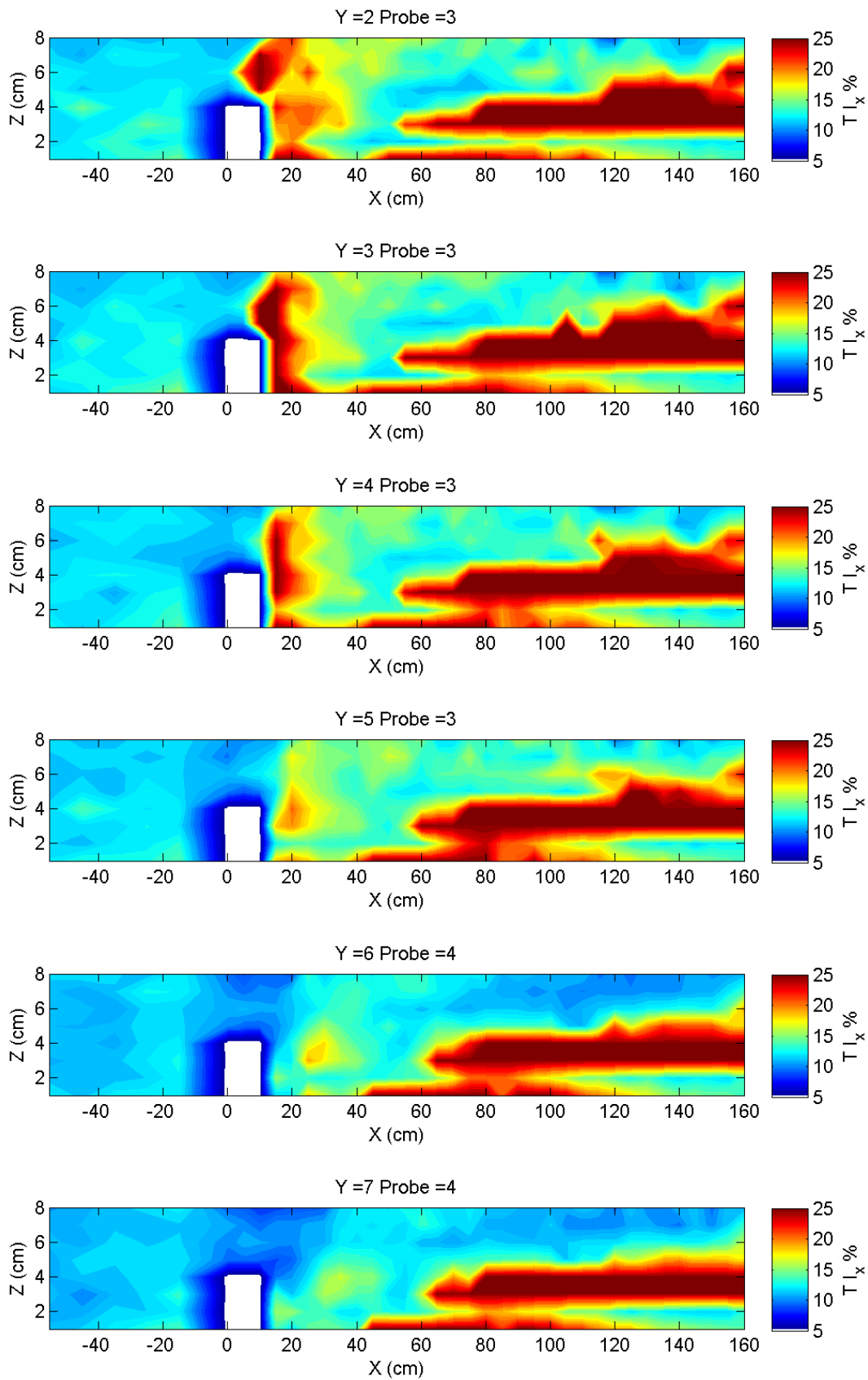


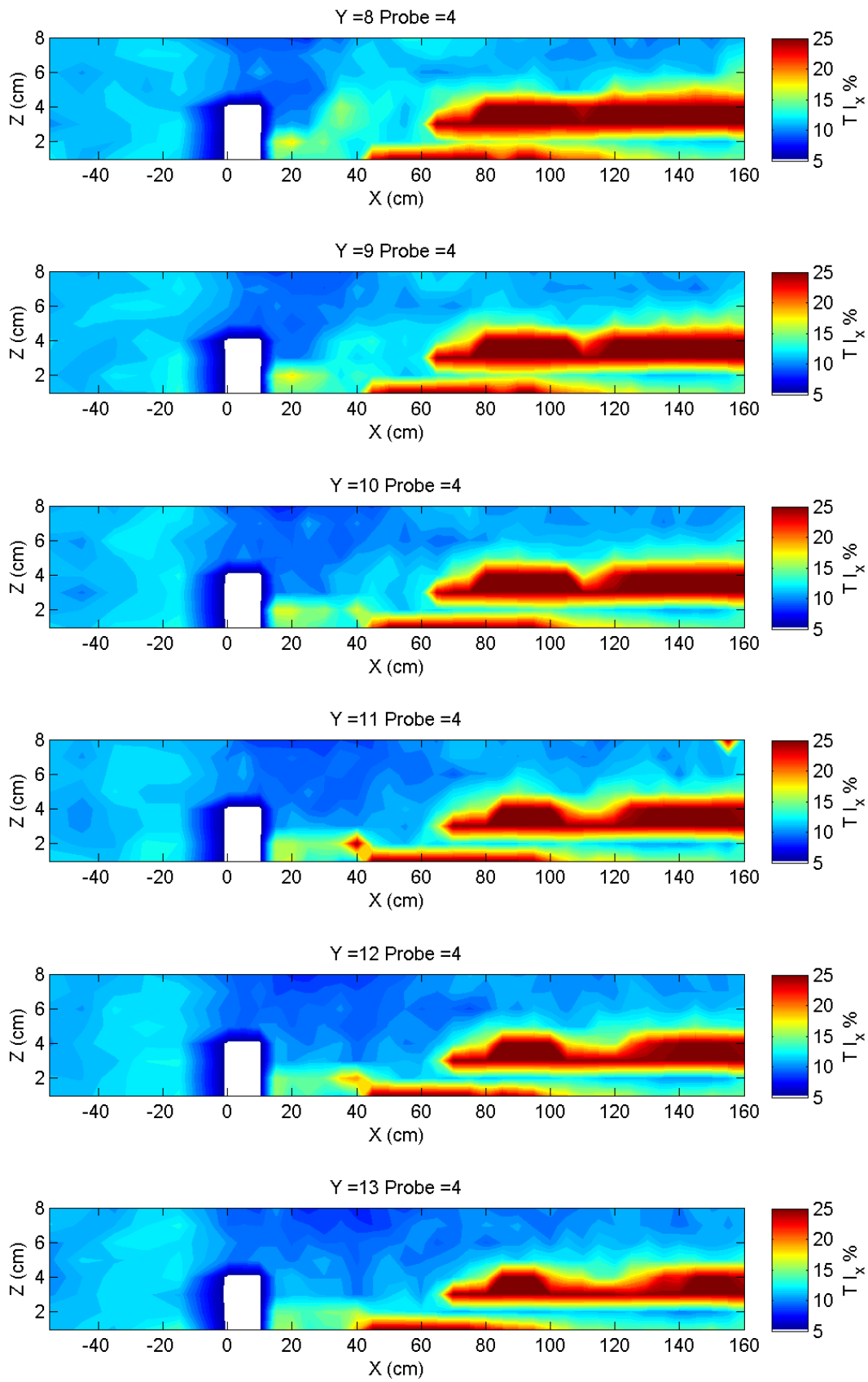


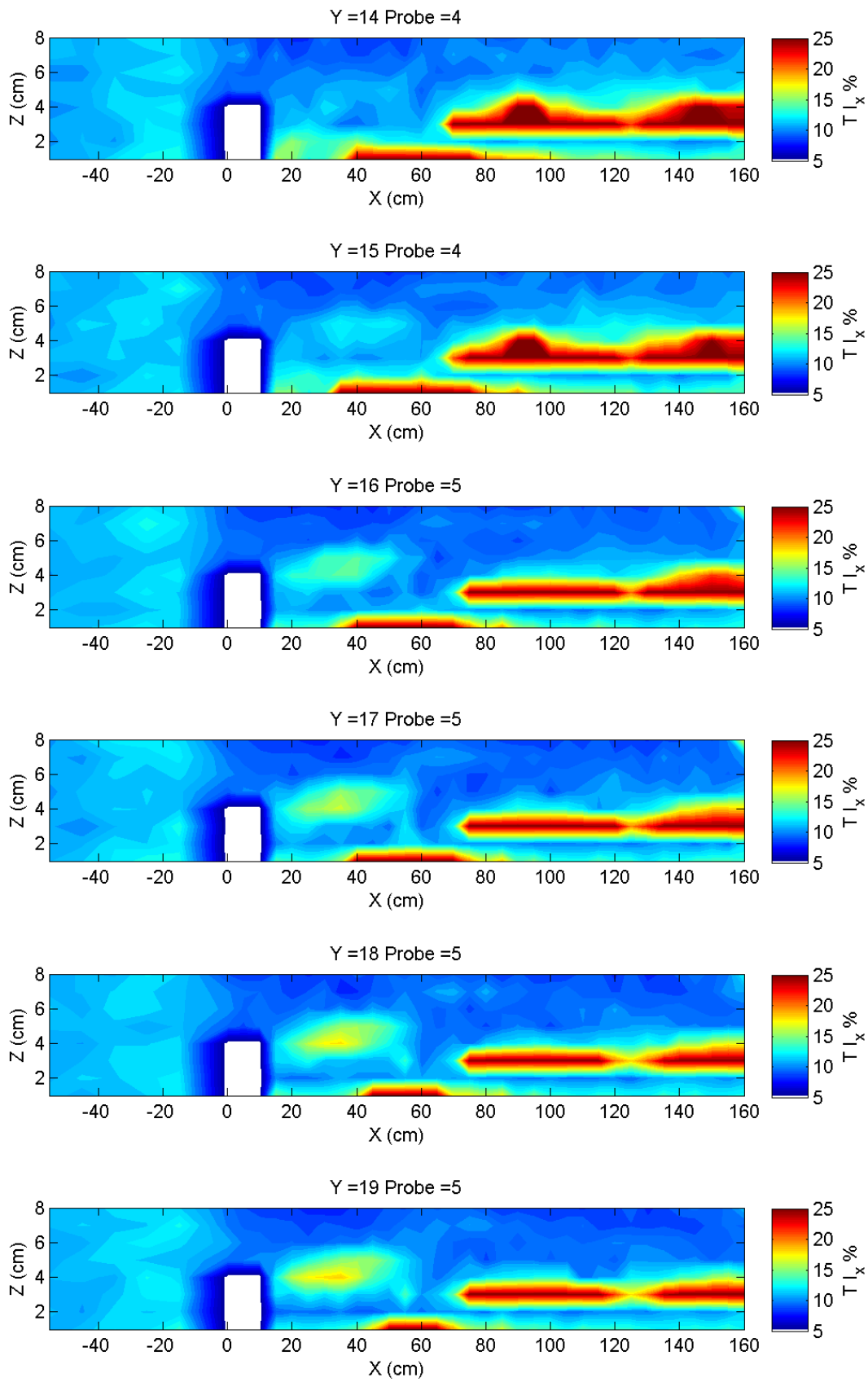




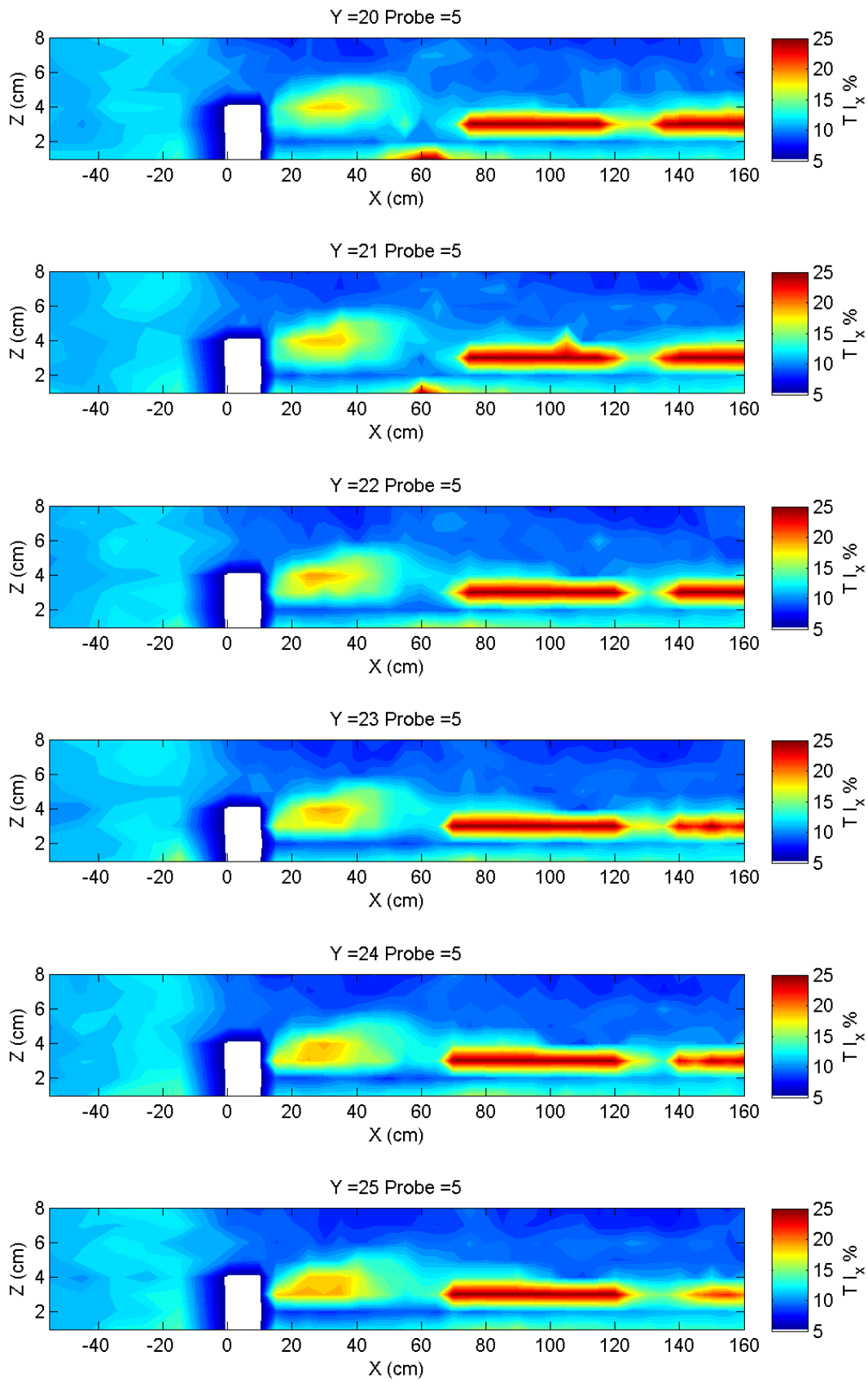


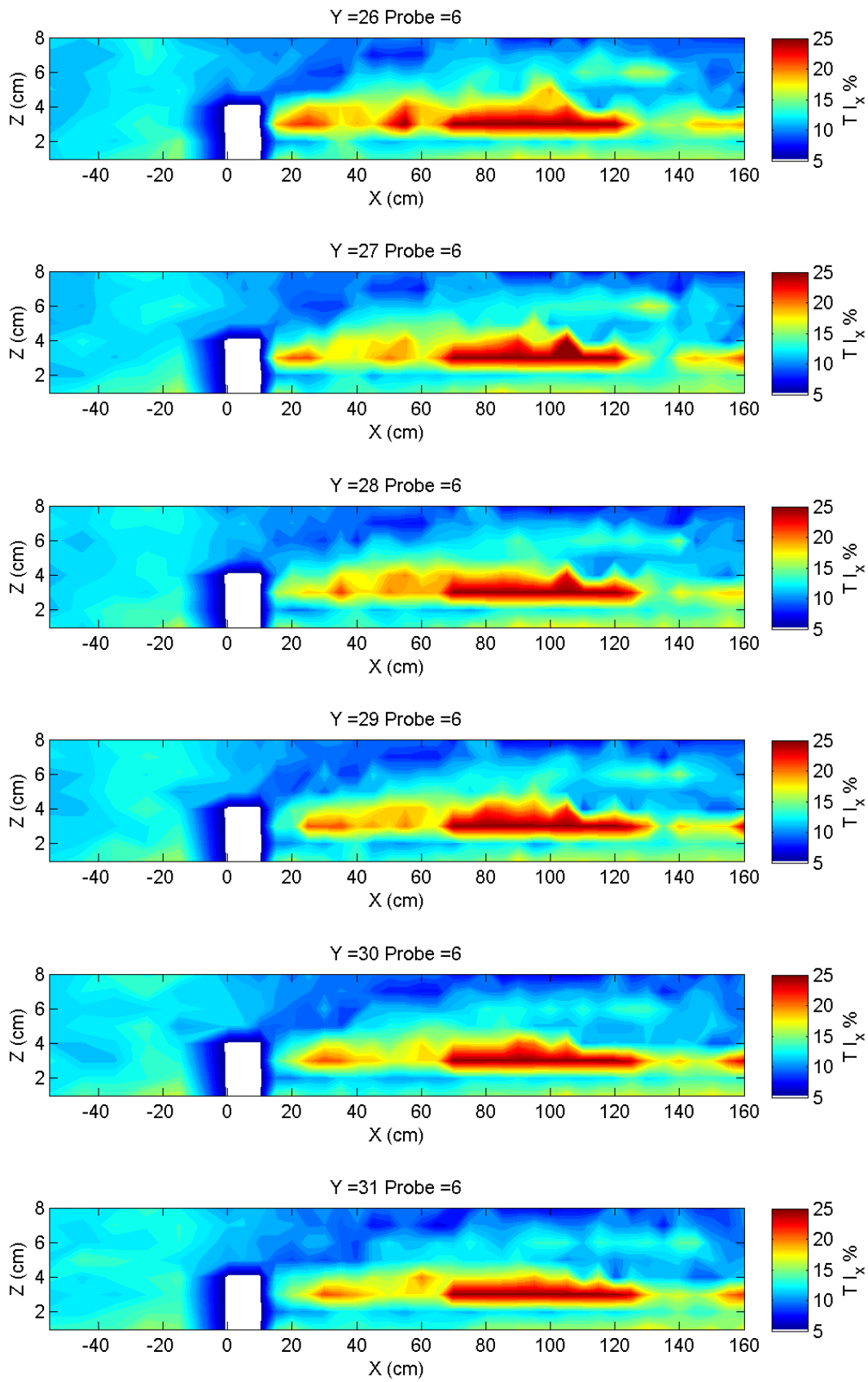


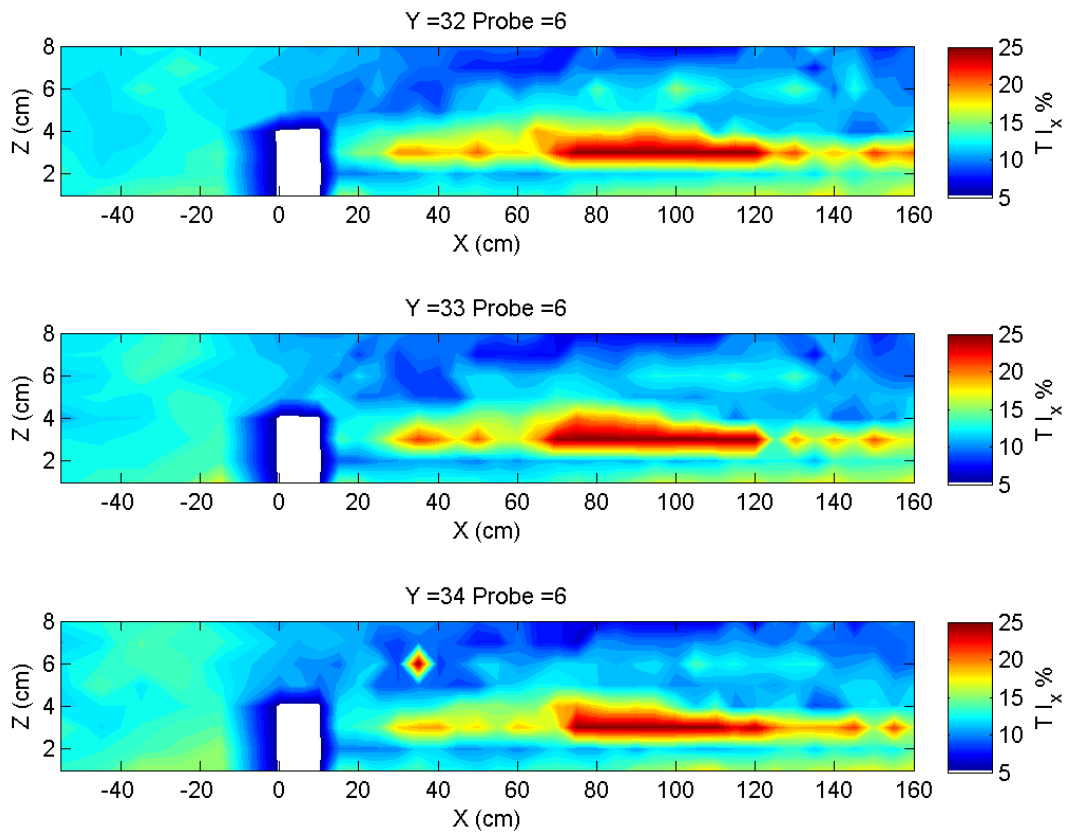




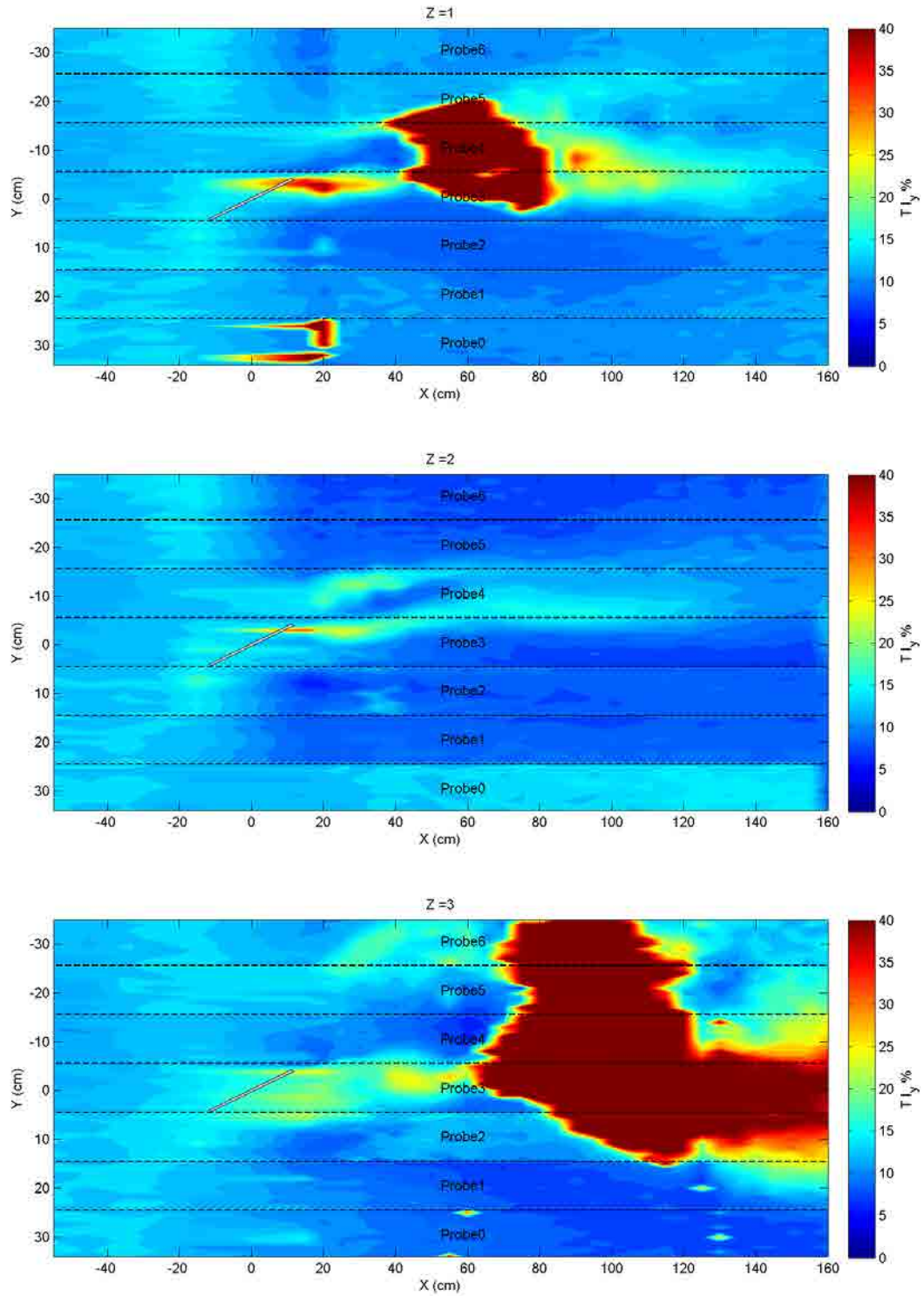


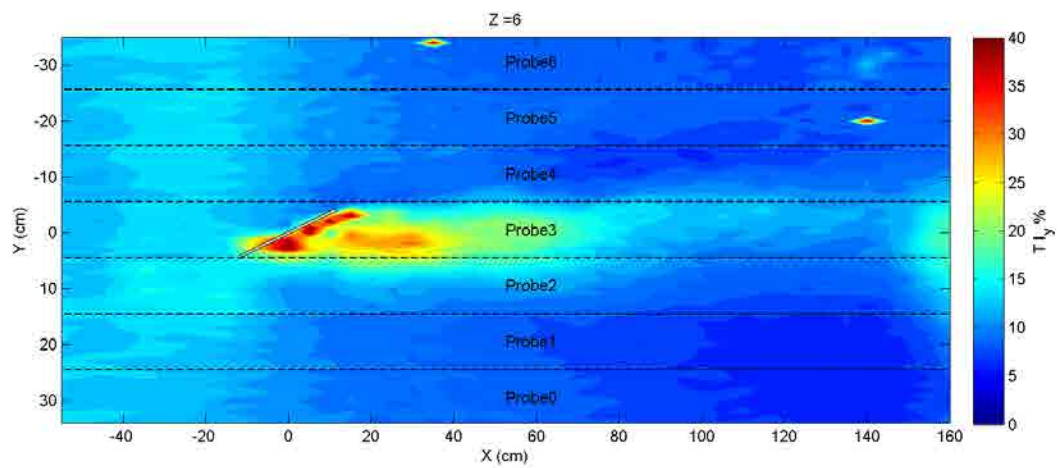
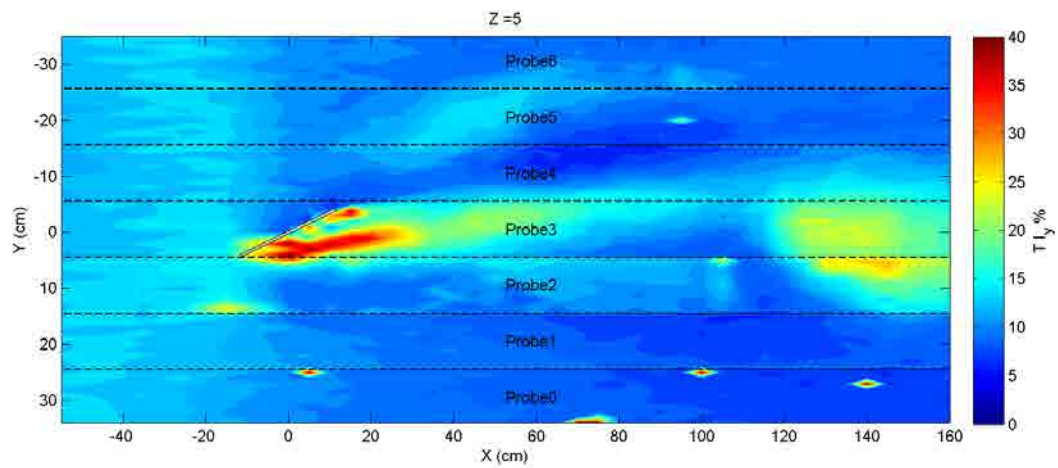
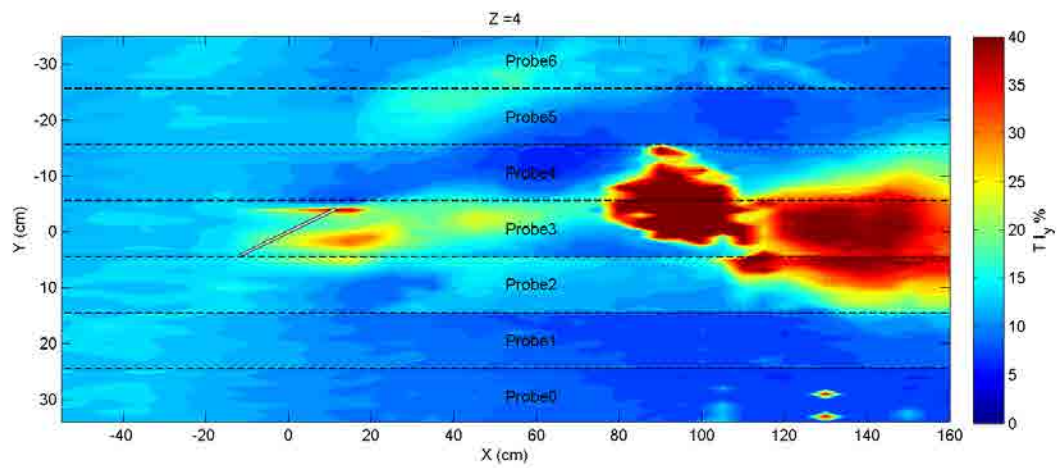


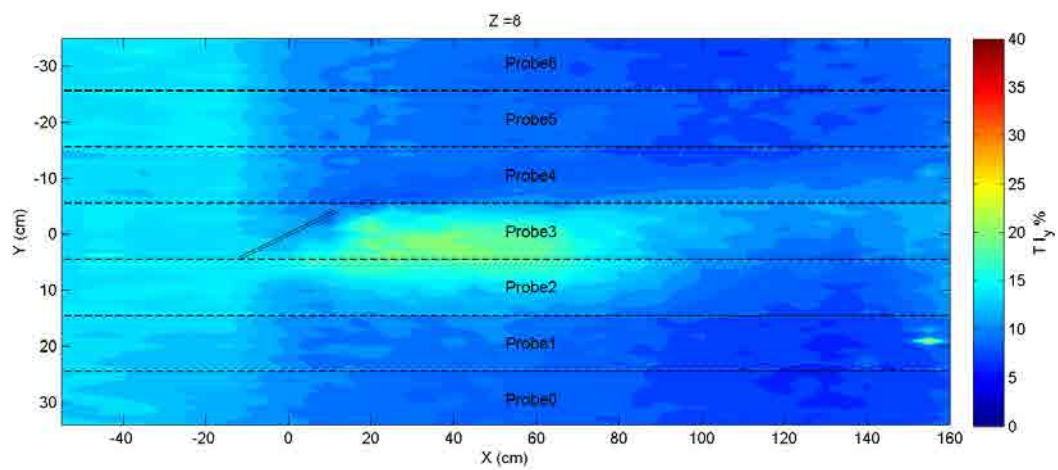
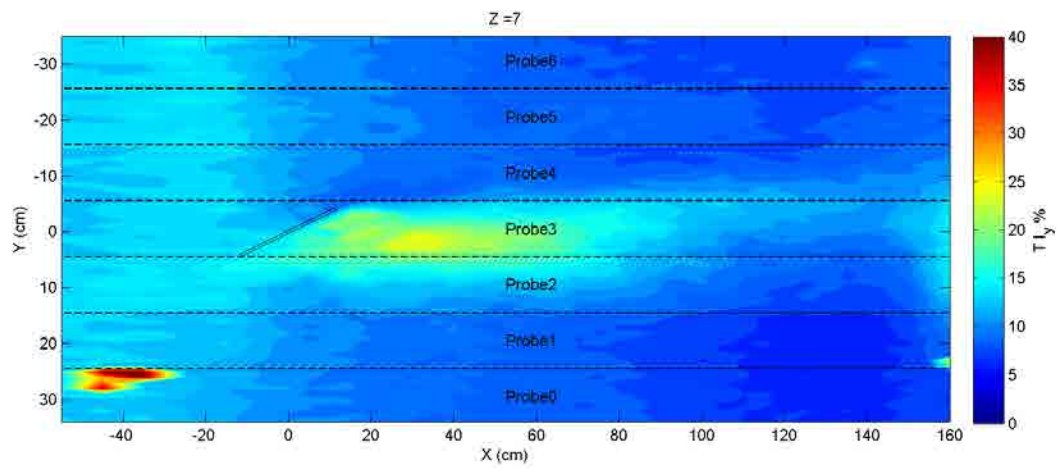




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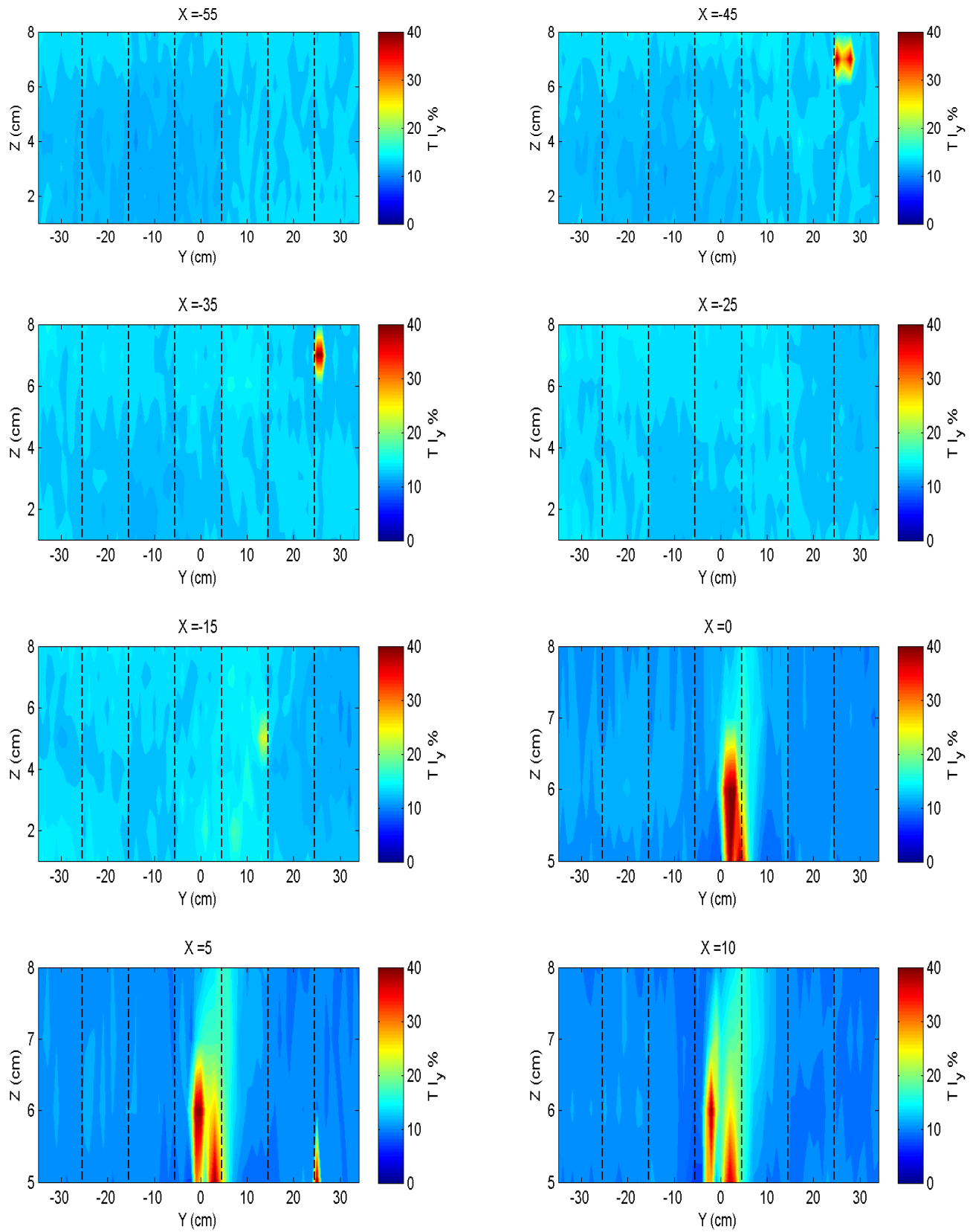


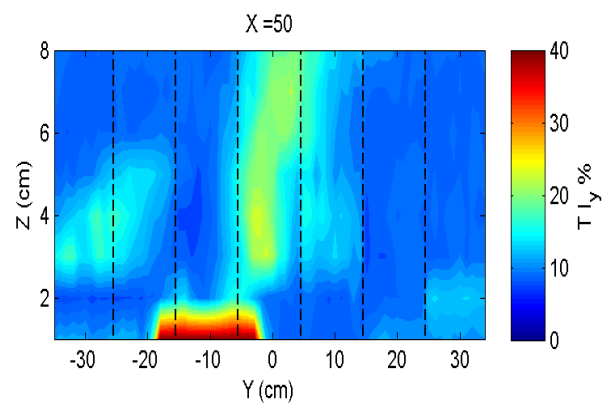
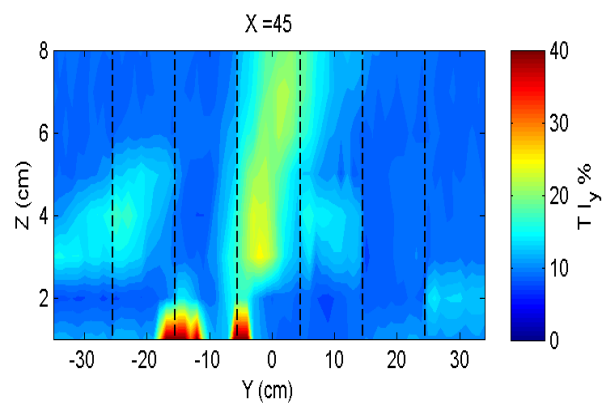
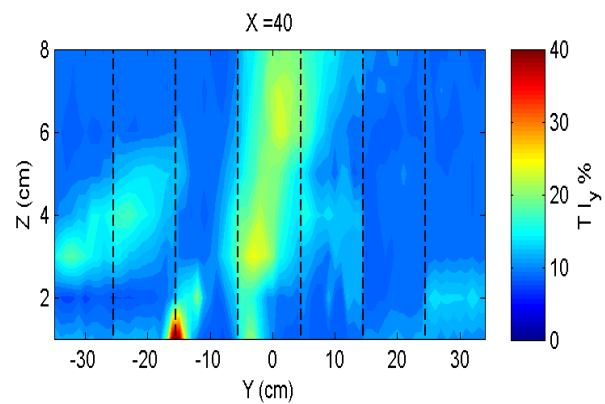
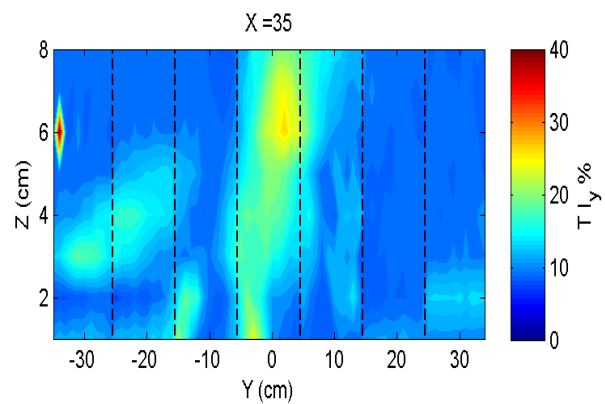
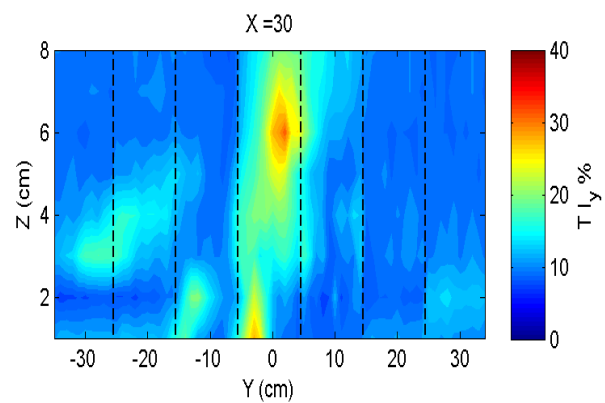
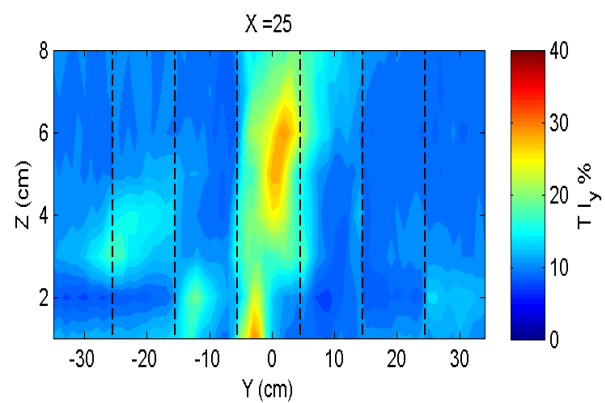
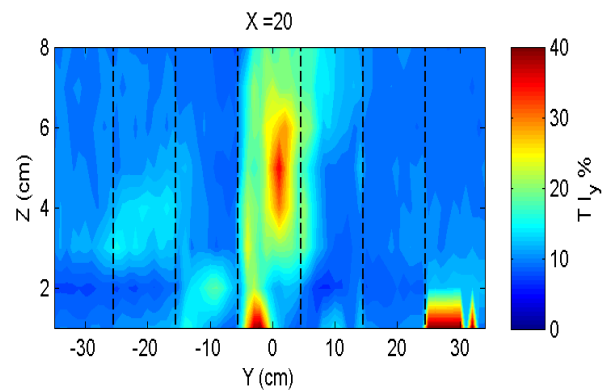
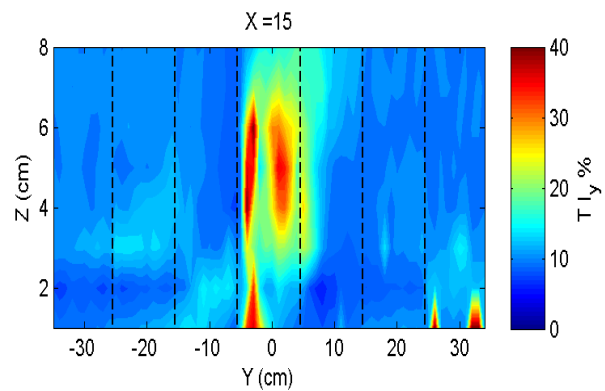




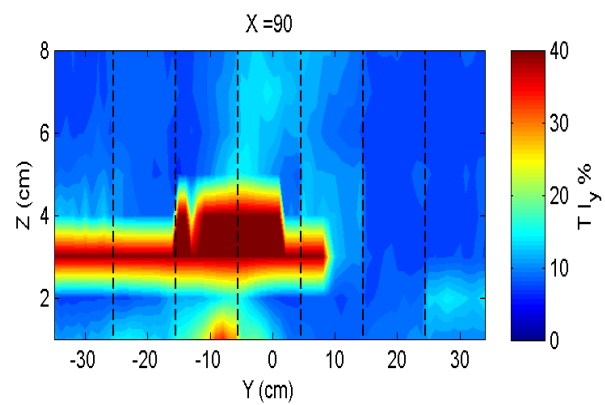
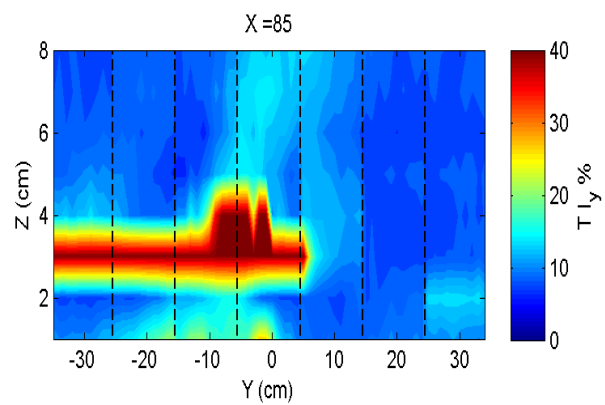
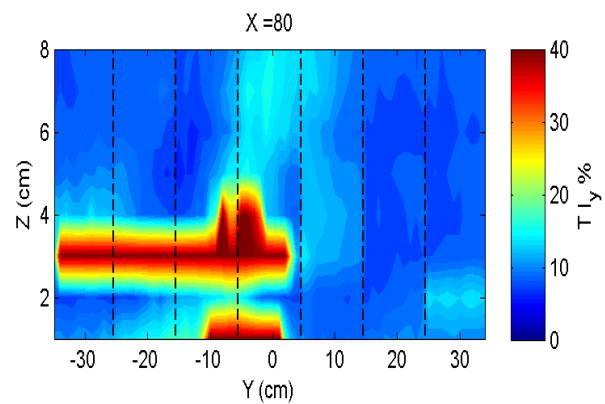
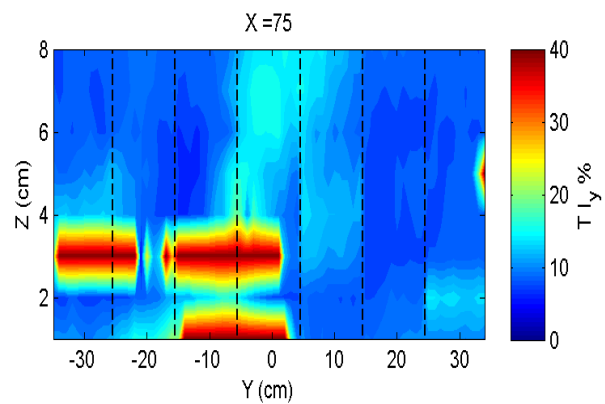
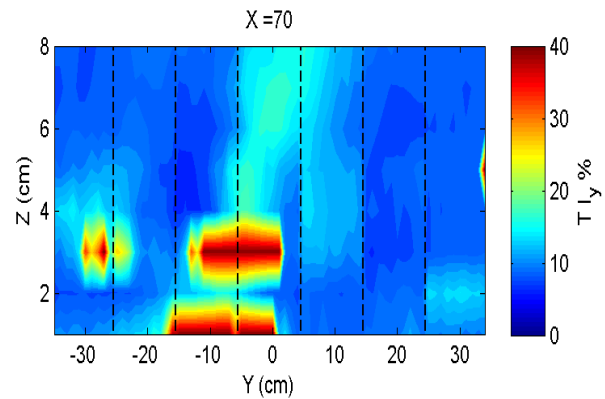
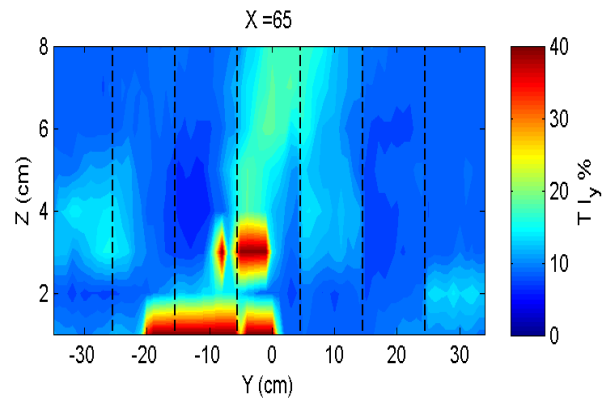
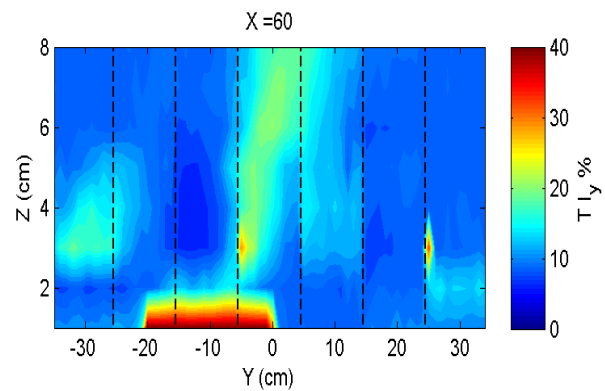
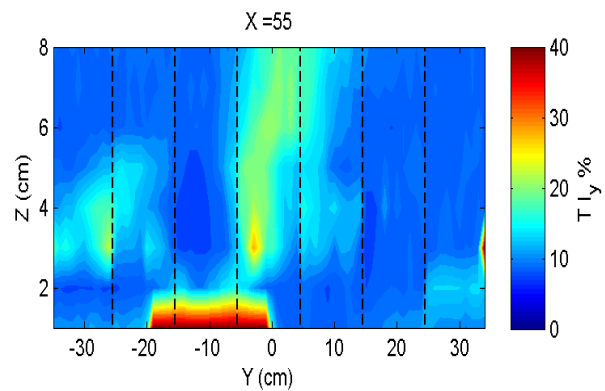


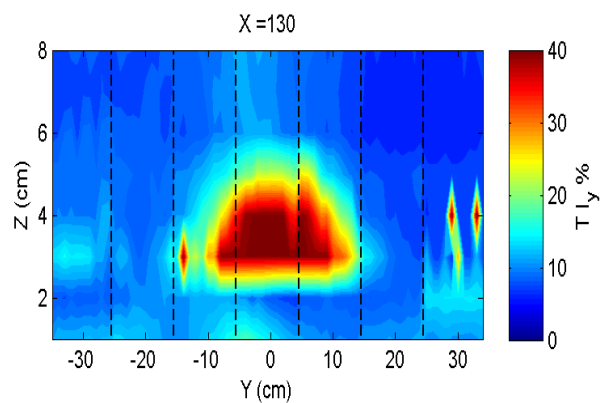
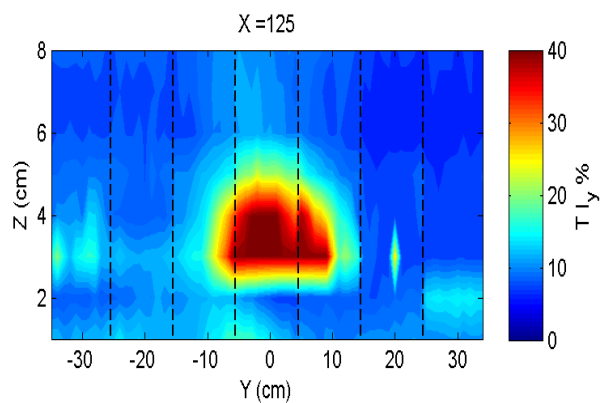
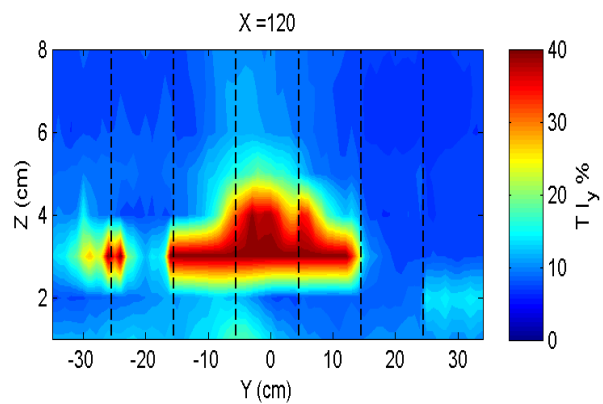
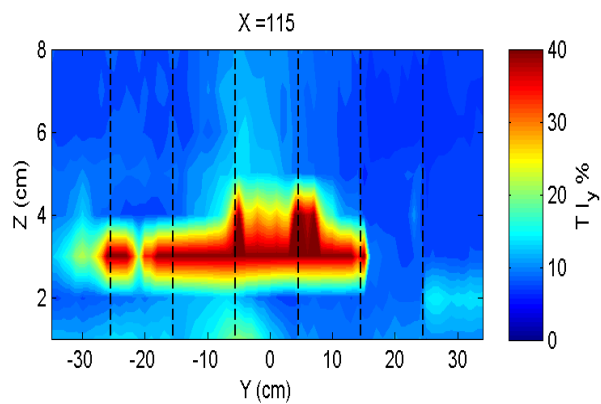
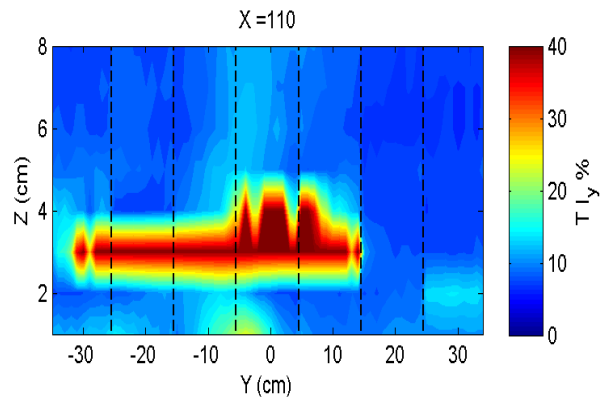
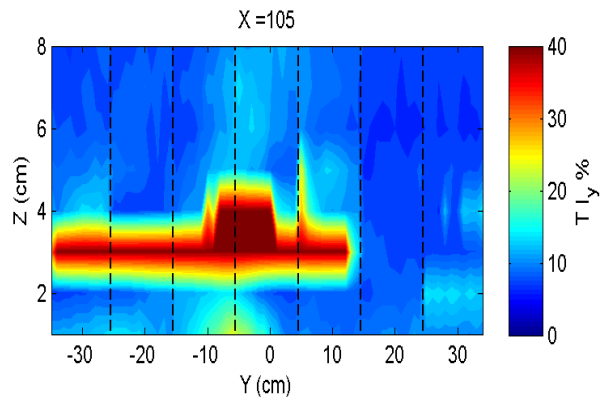
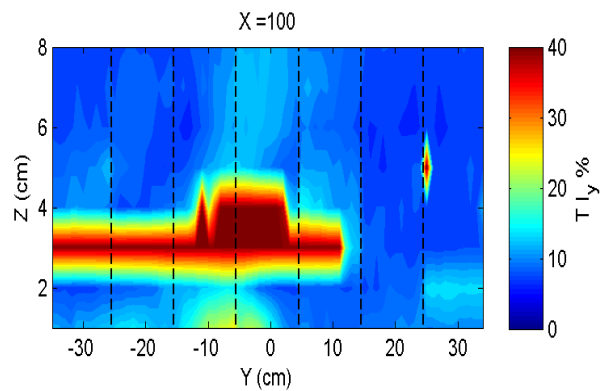
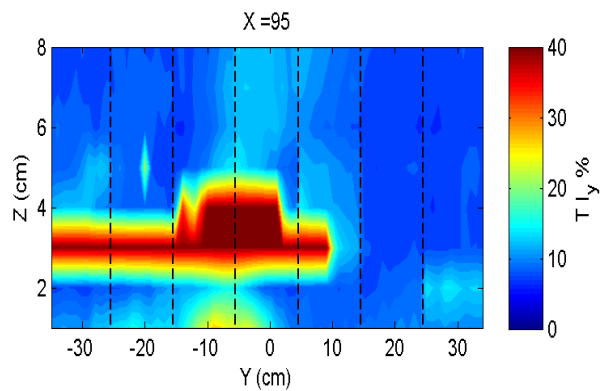
## Turbulence Intensity $T.I_y$ in y and z-Directions

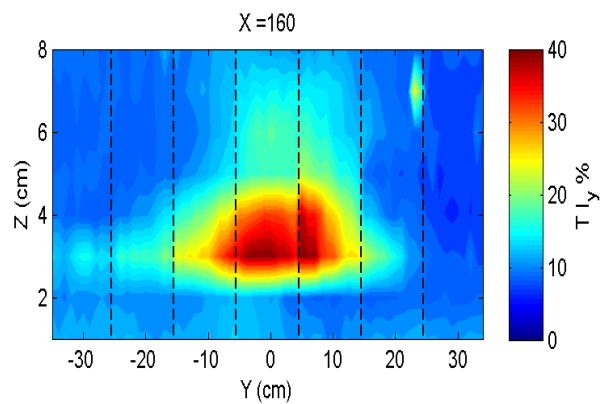
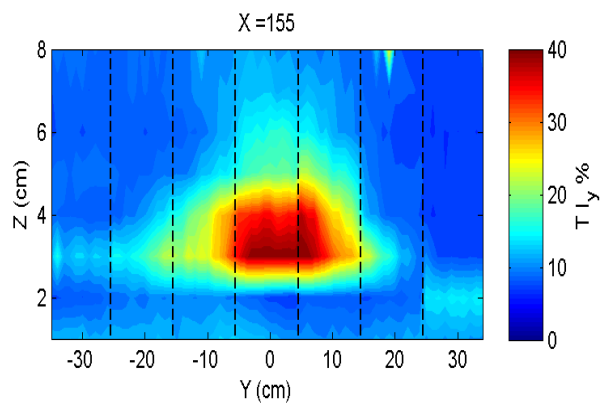
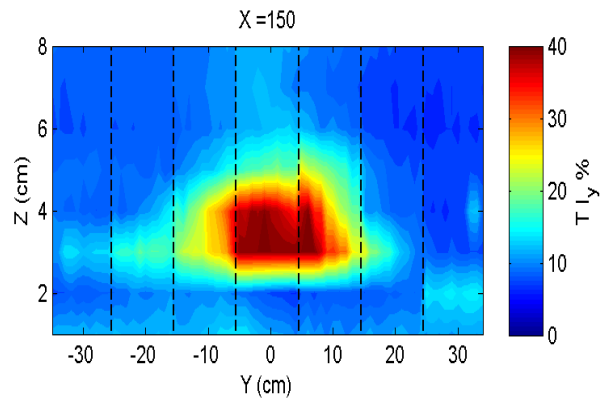
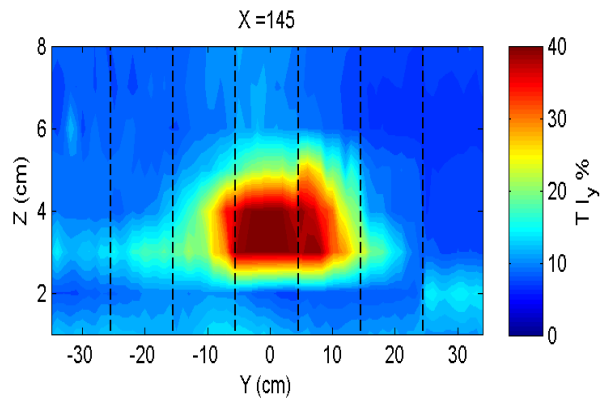
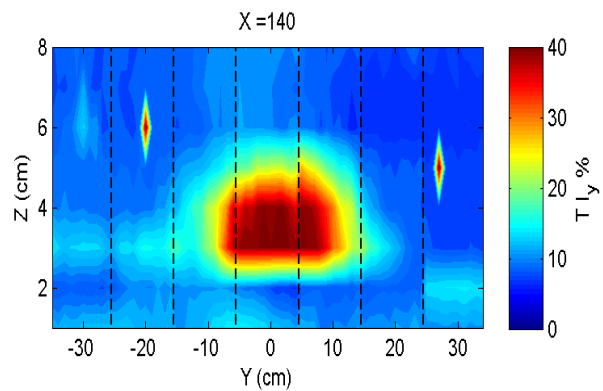
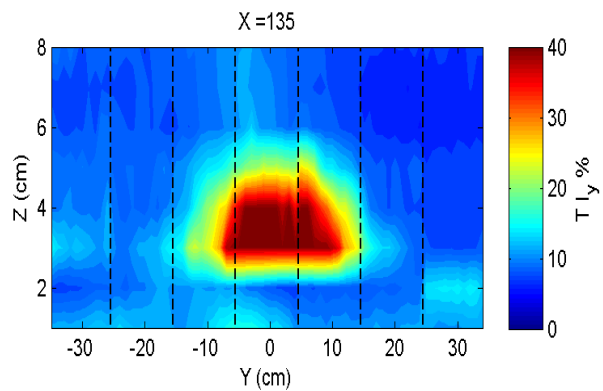




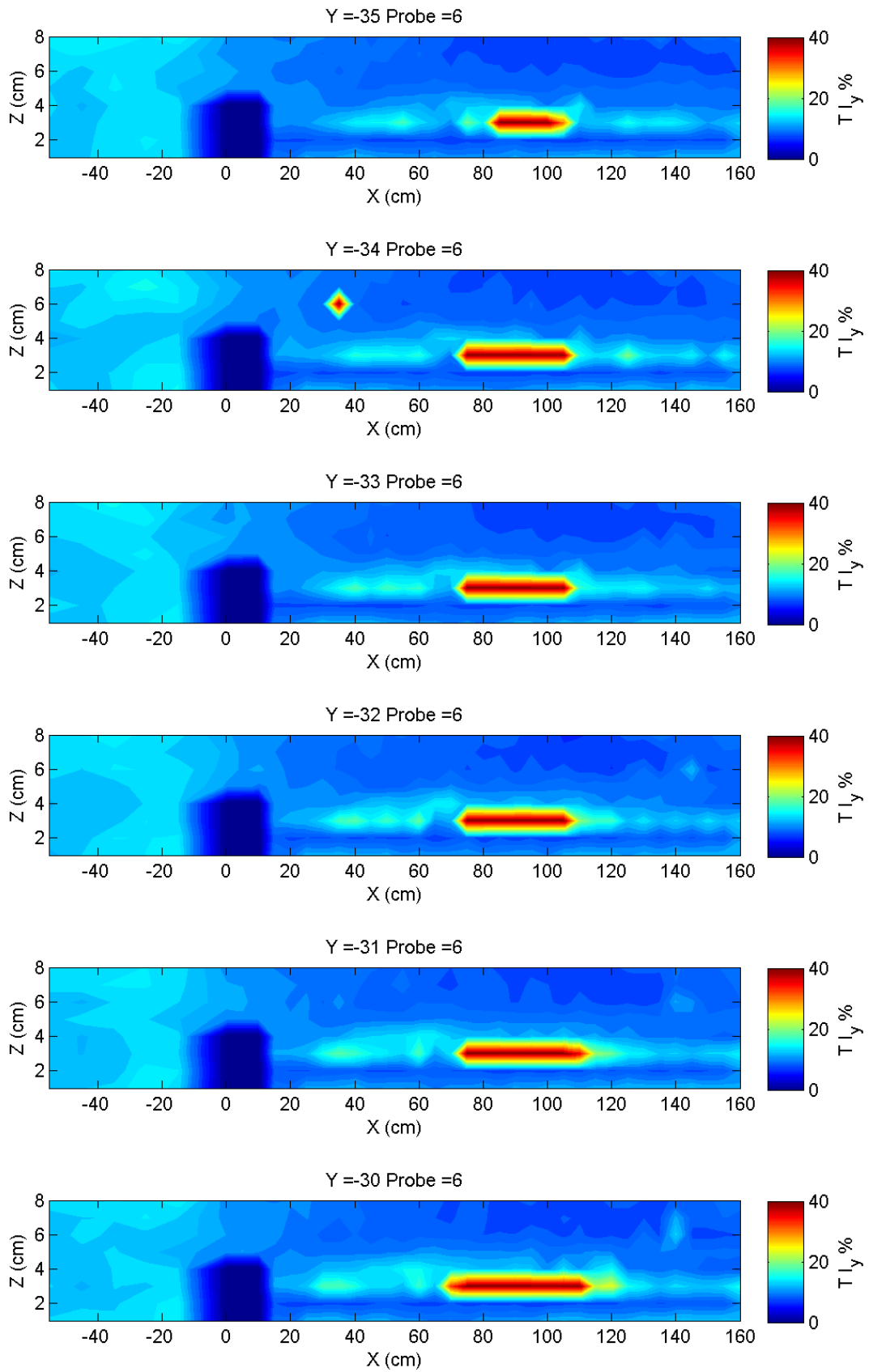


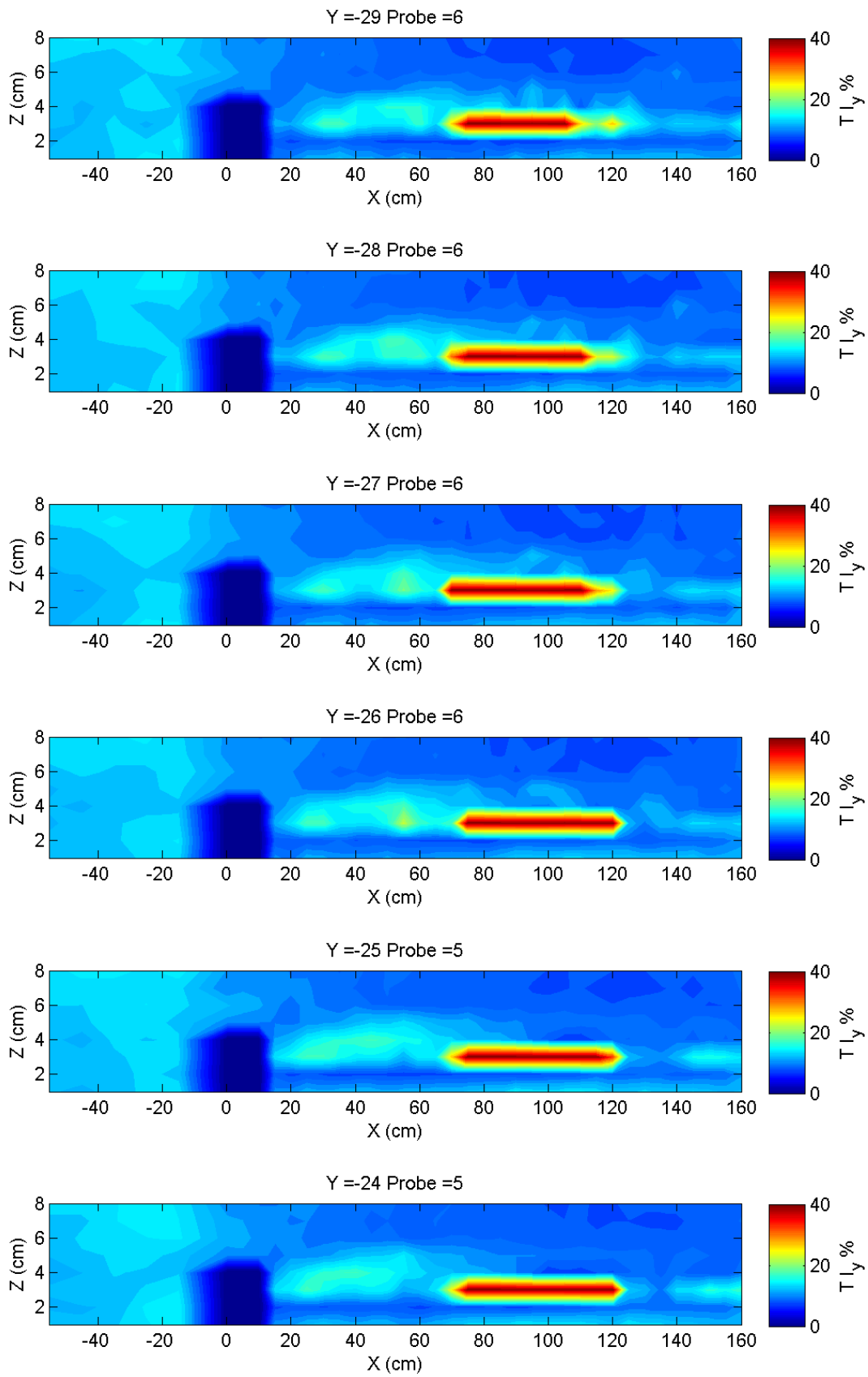


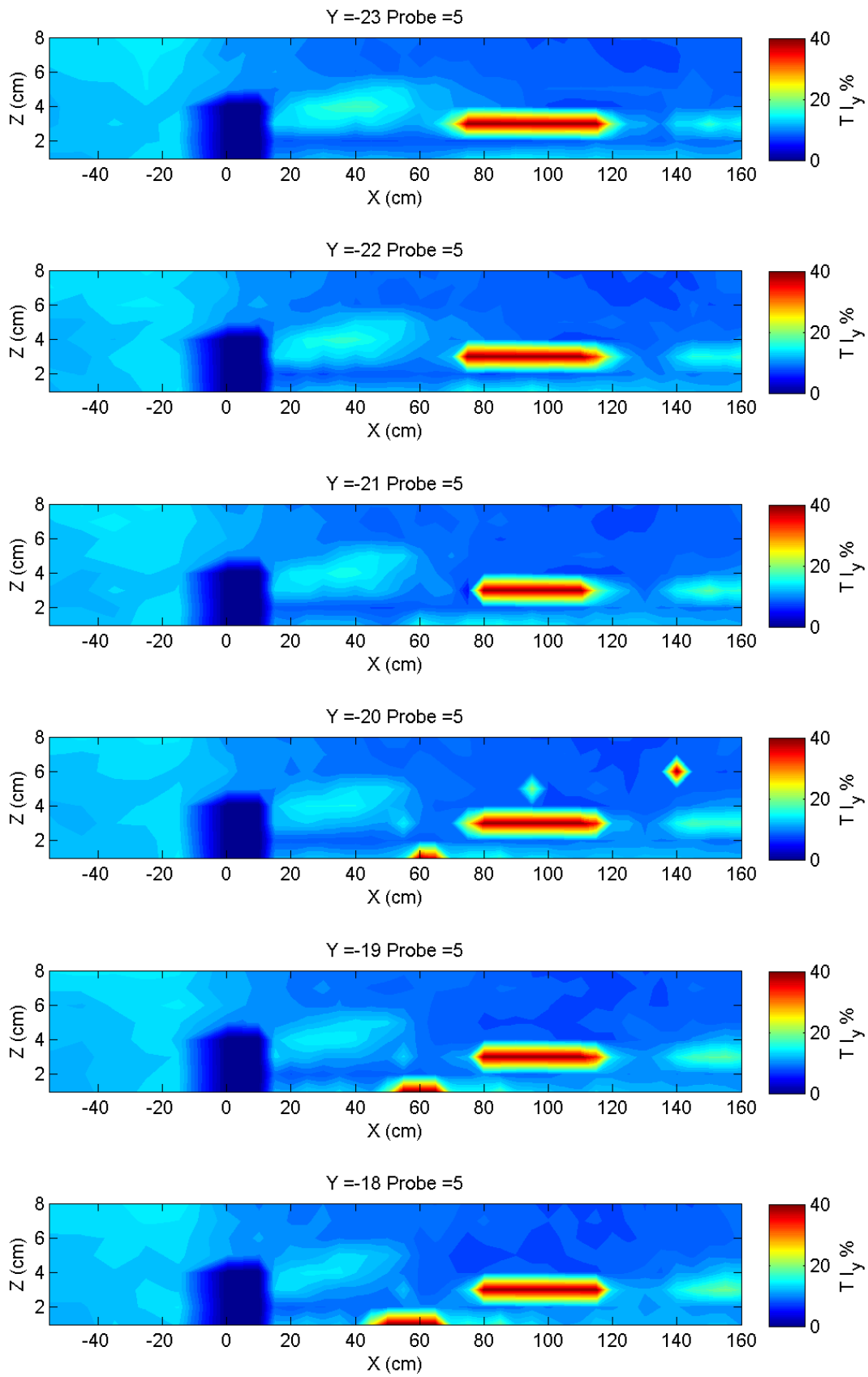


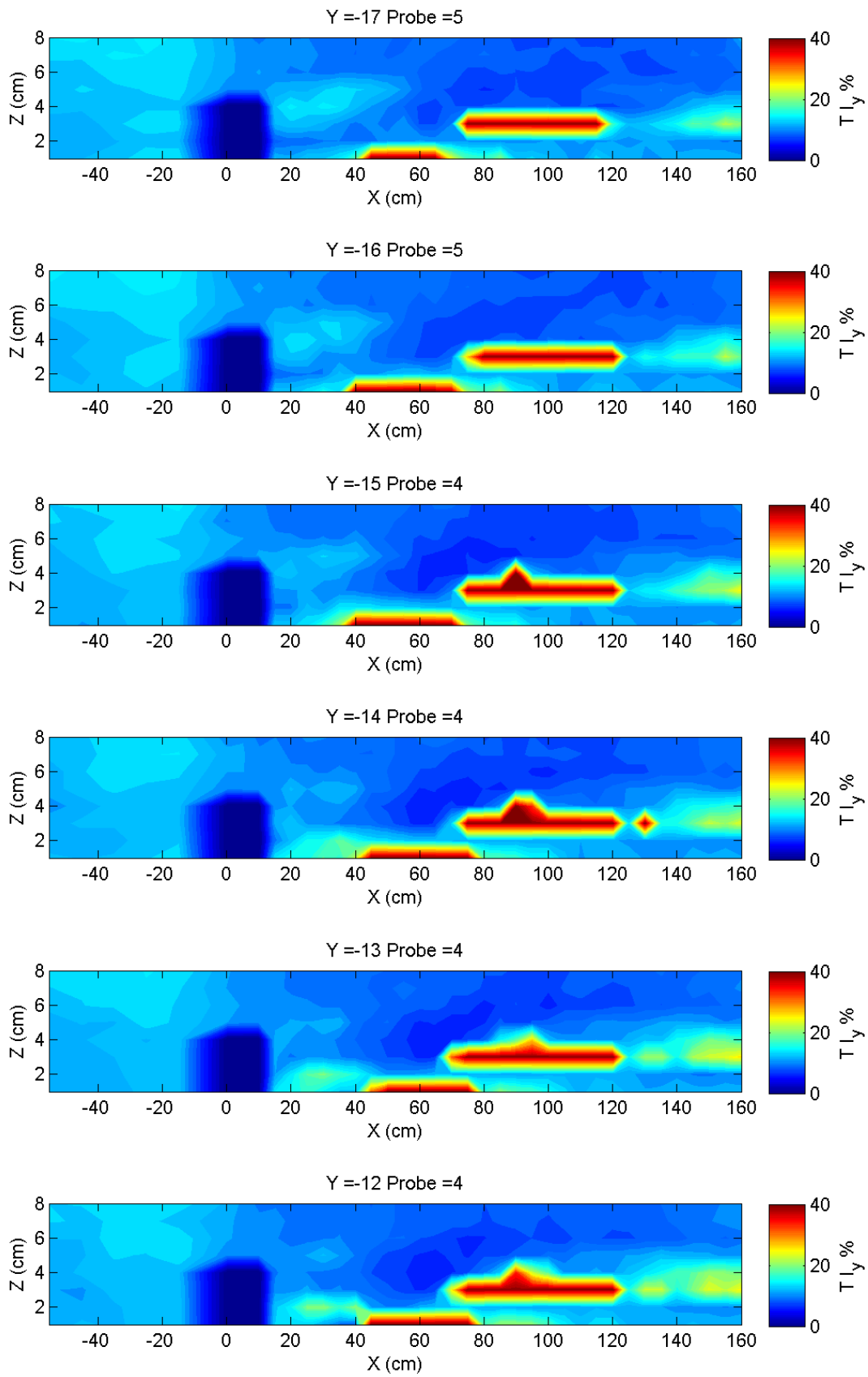


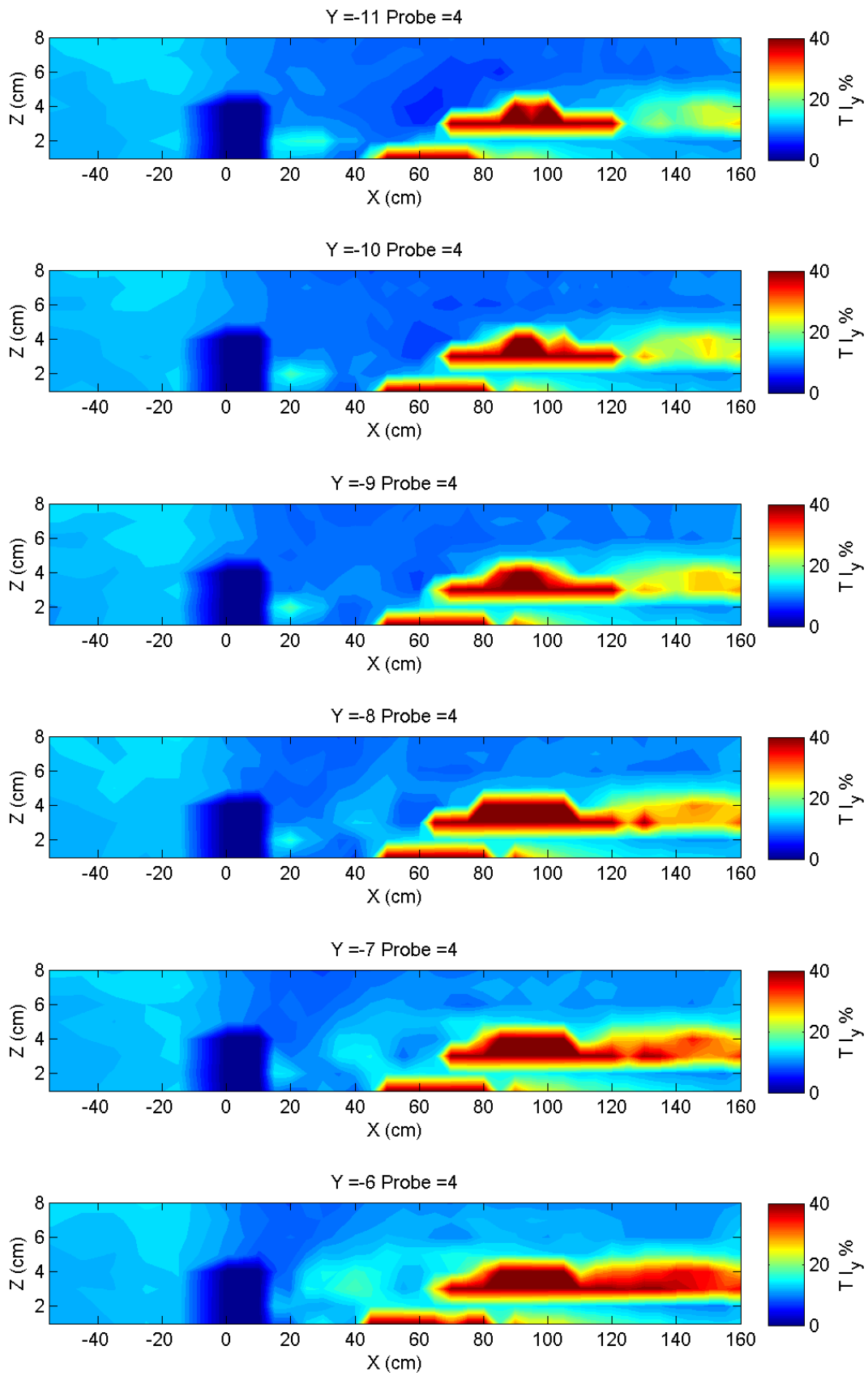
## Turbulence Intensity $T.I_y$ in x and z-Directions



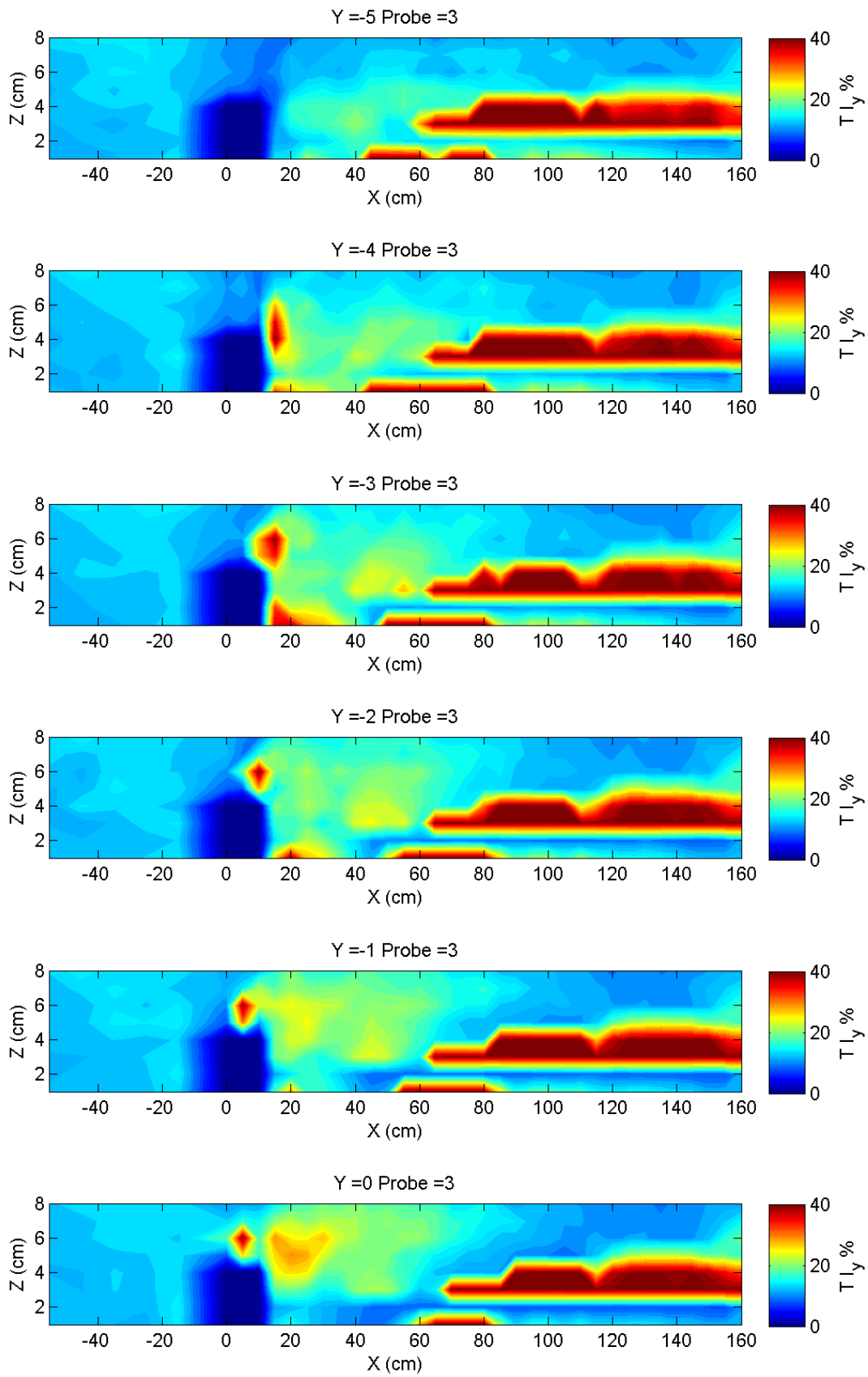


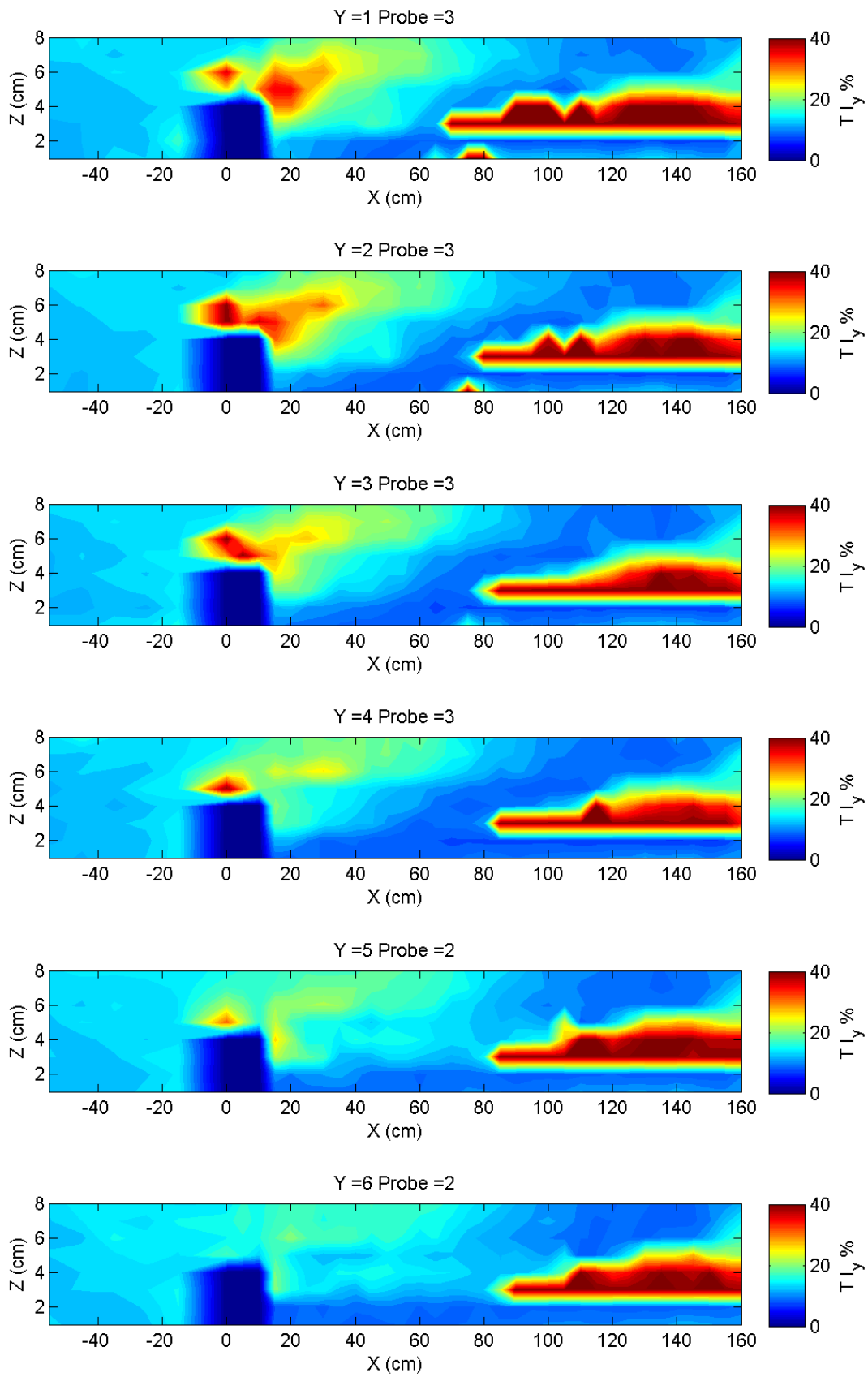


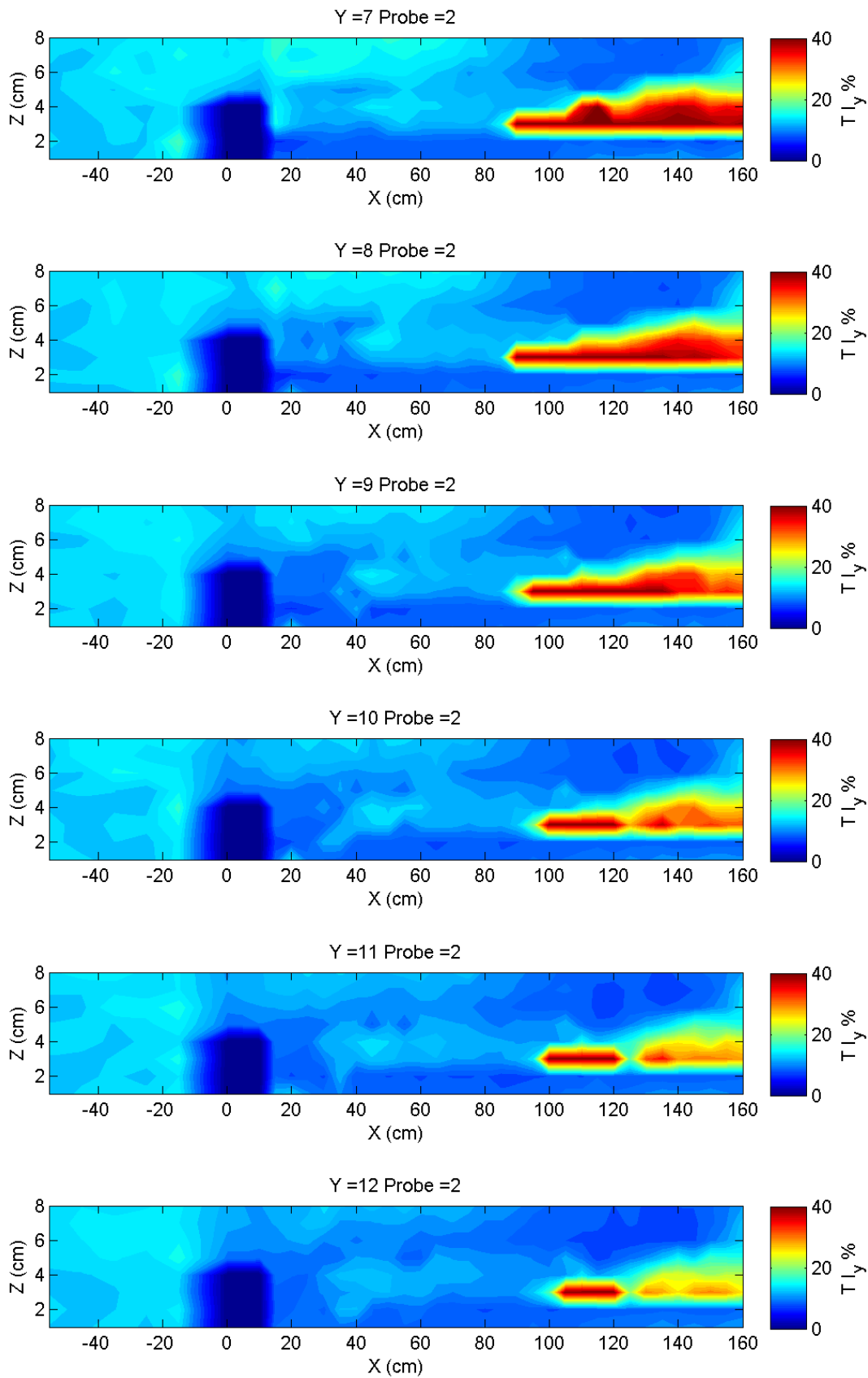


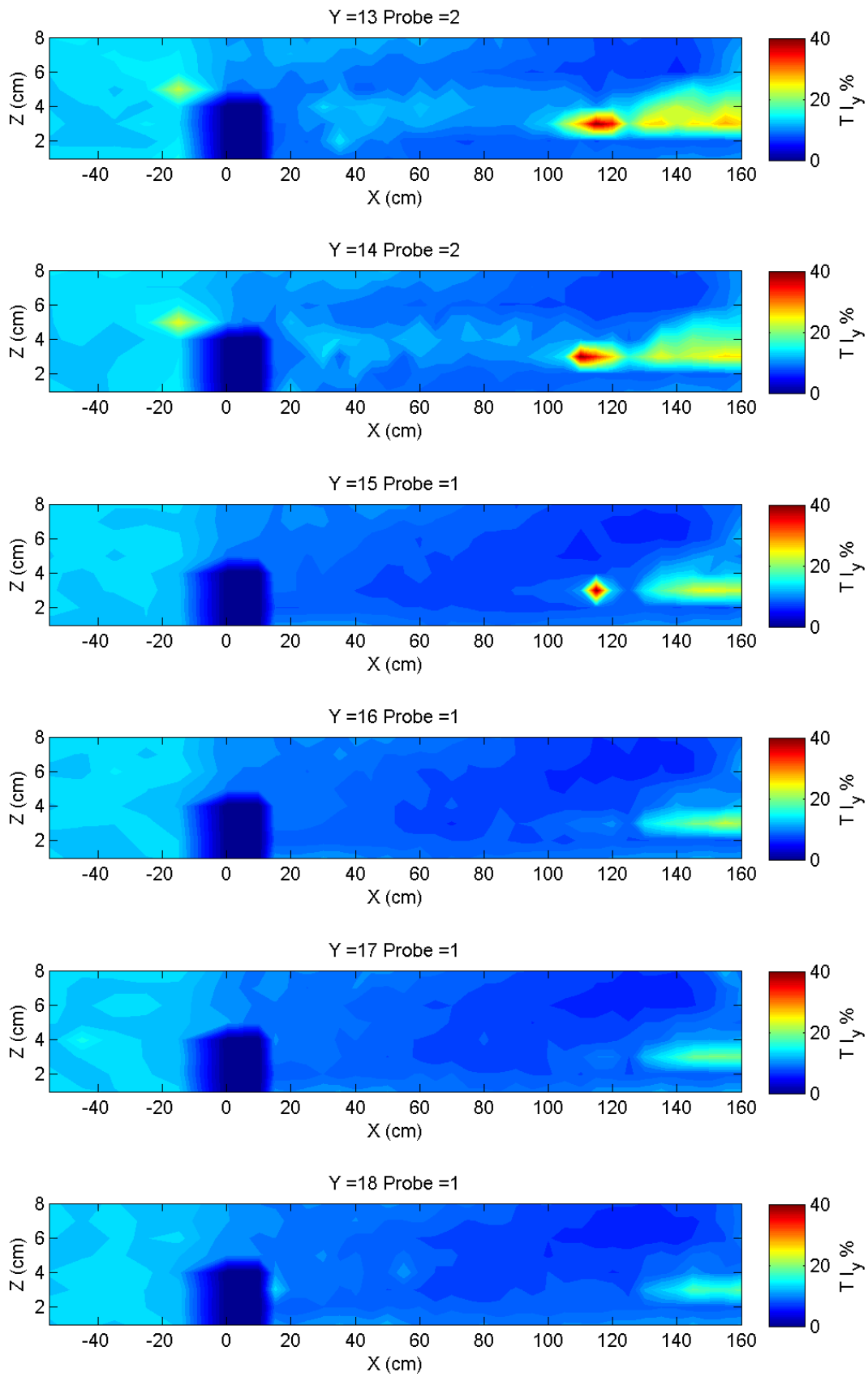


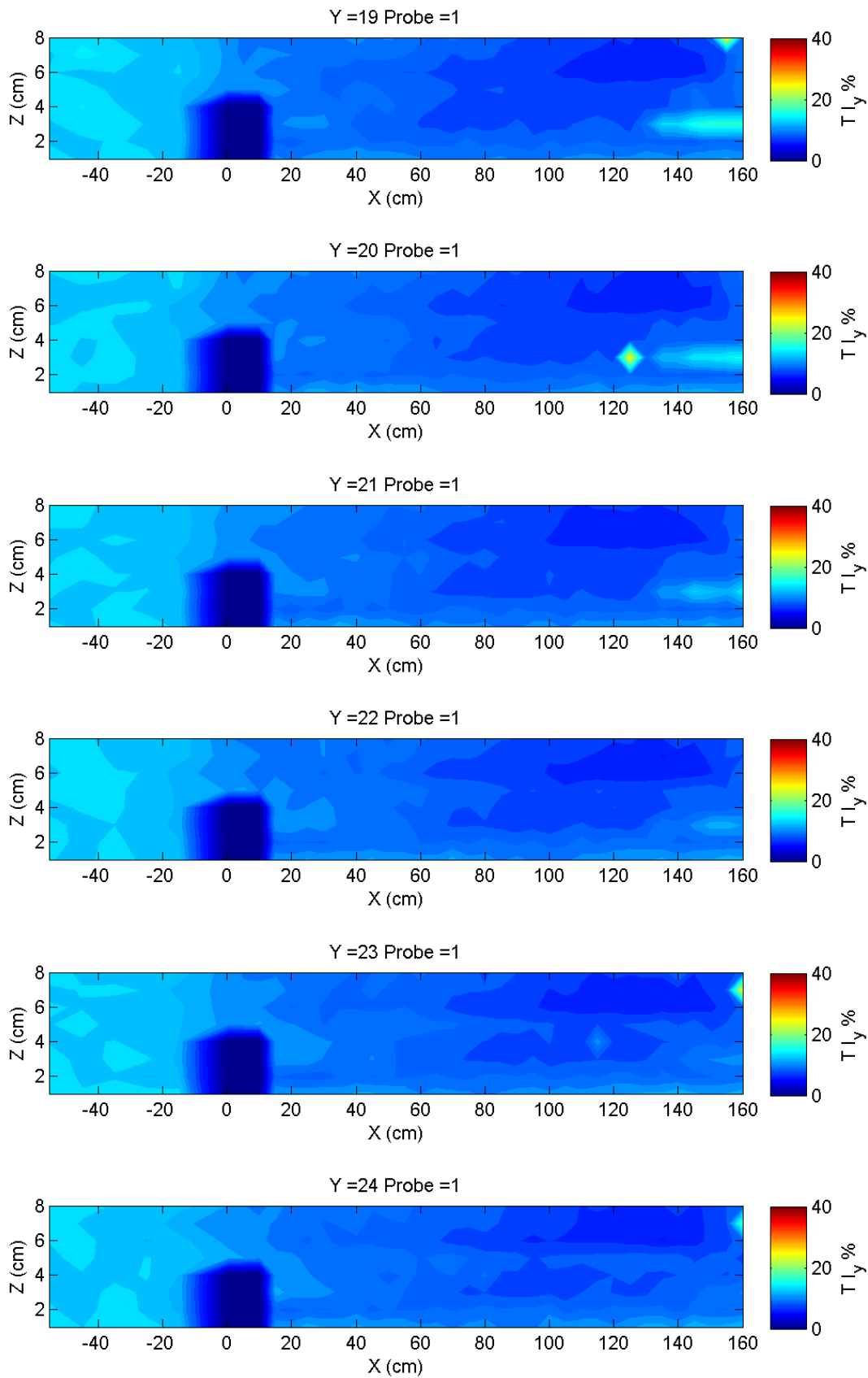


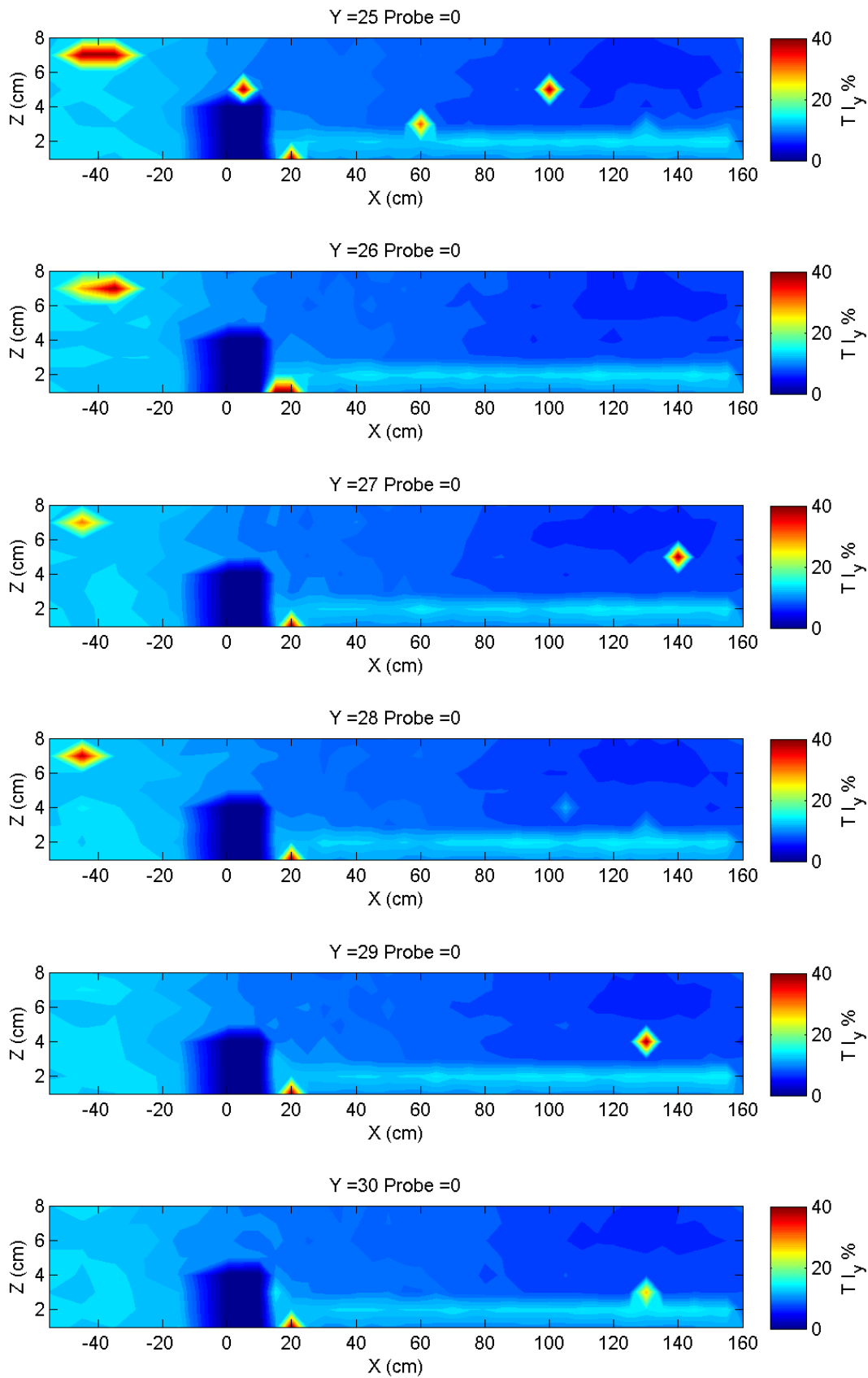


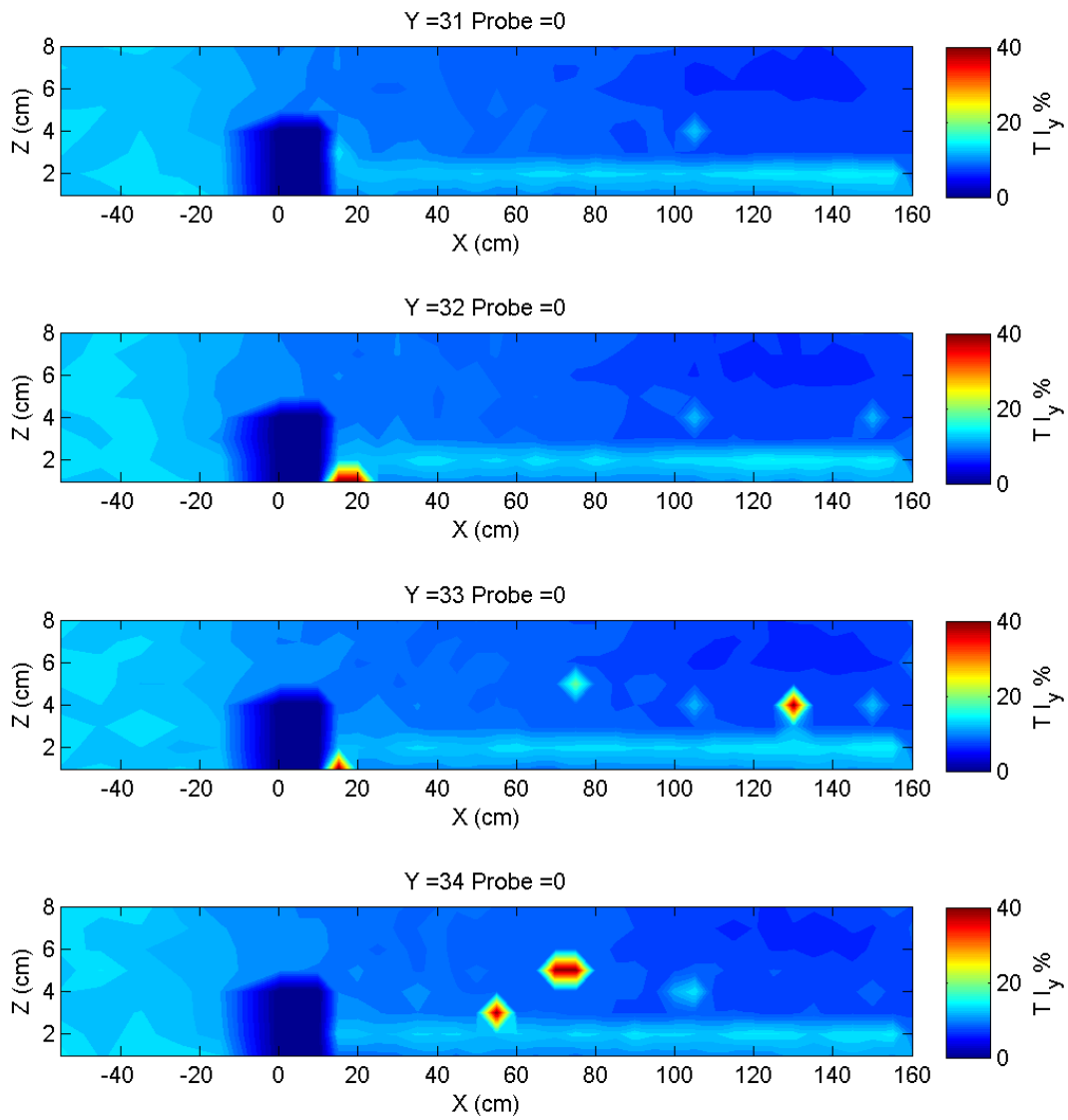




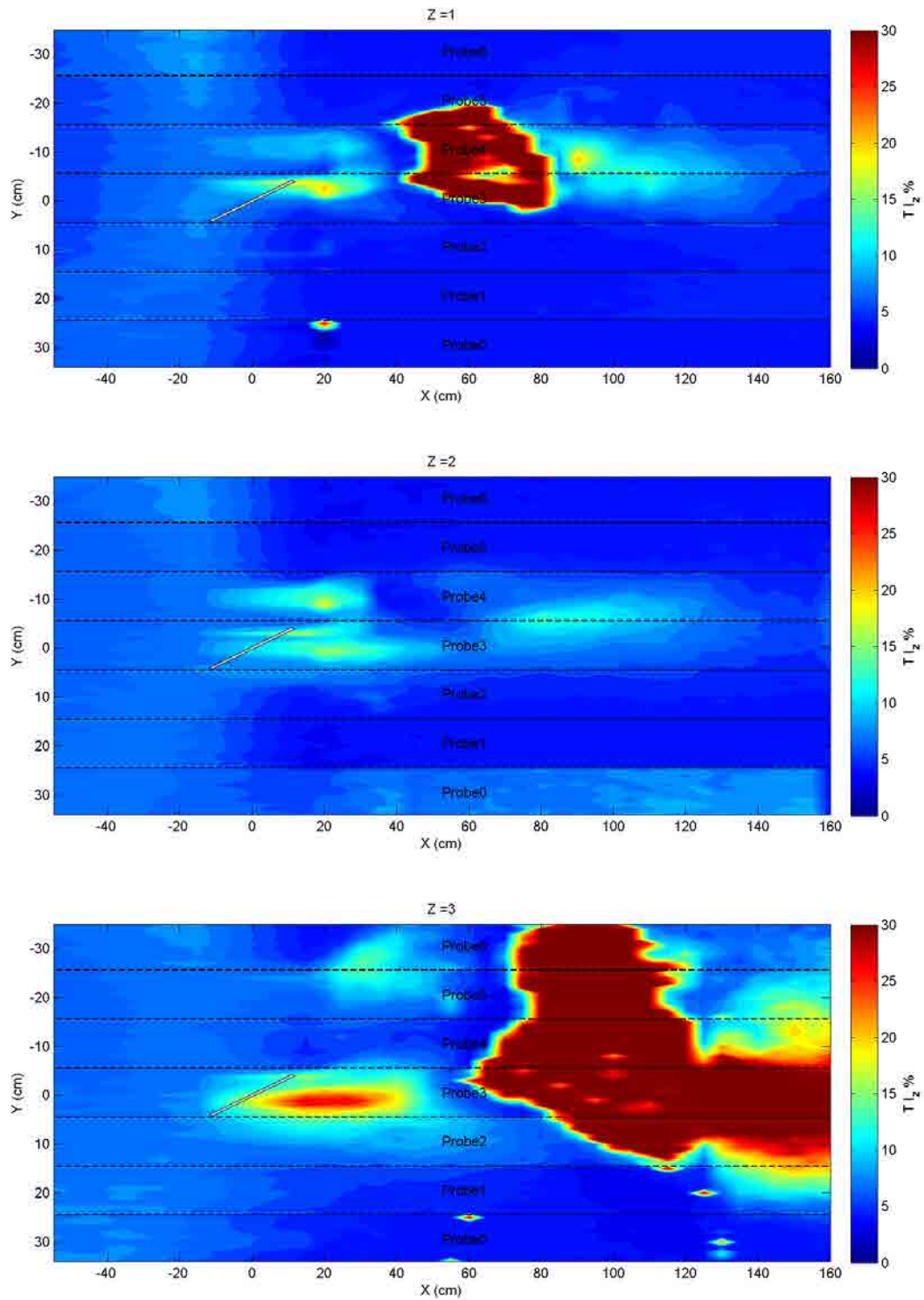




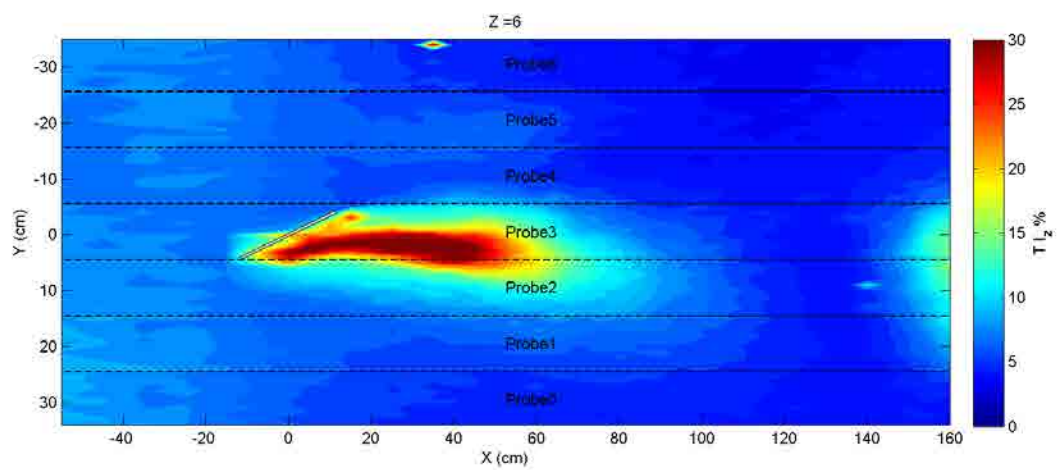
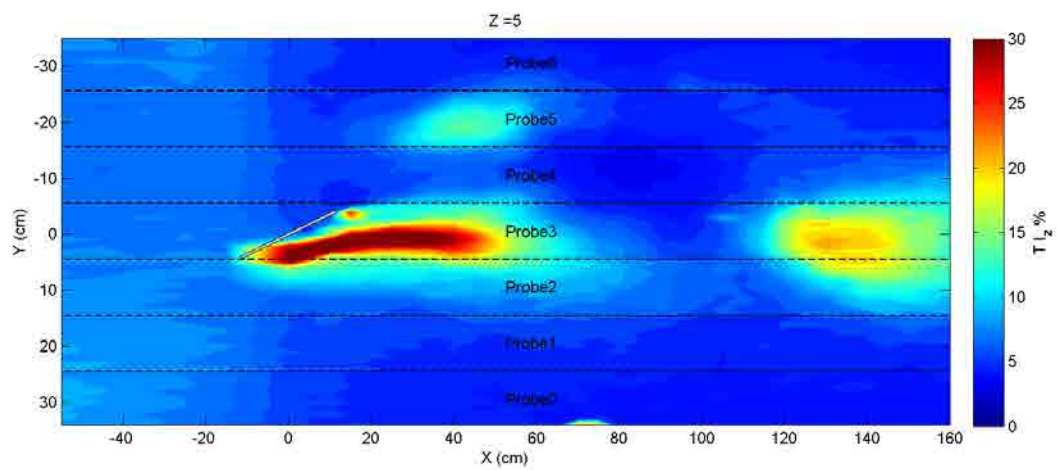
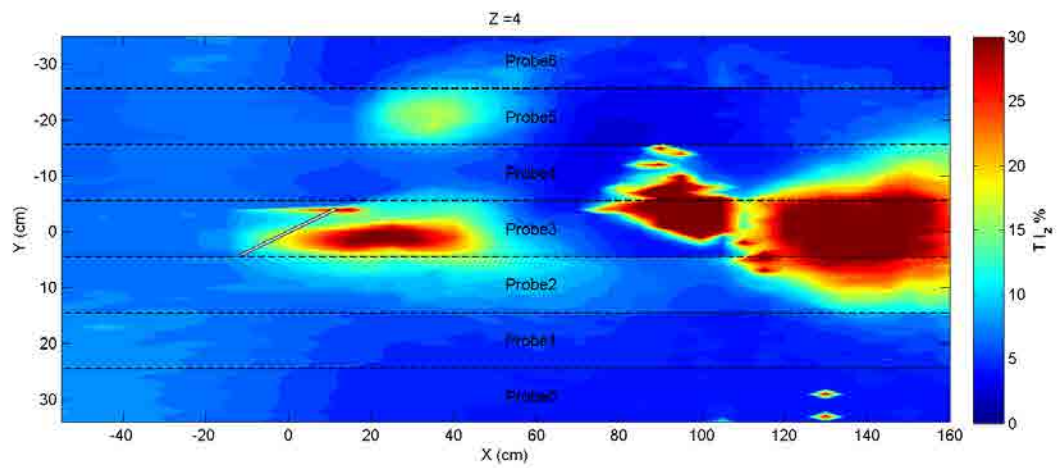


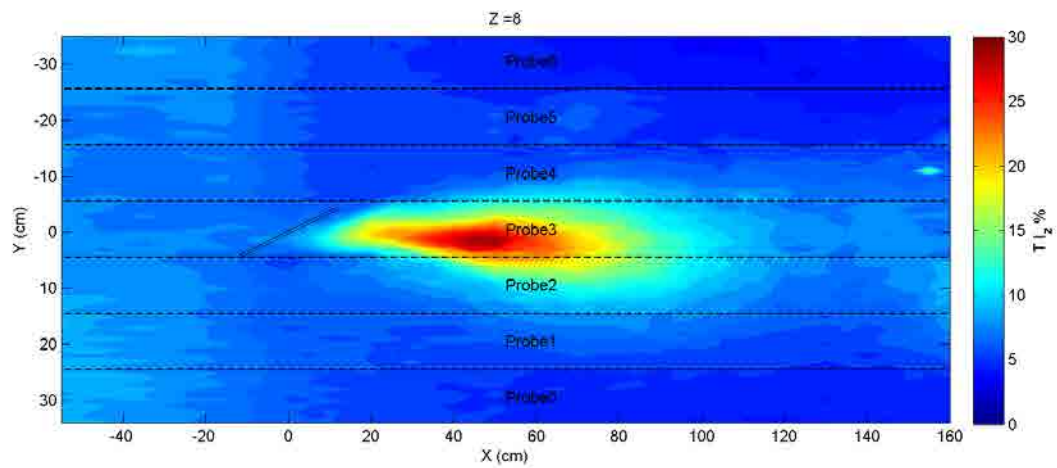
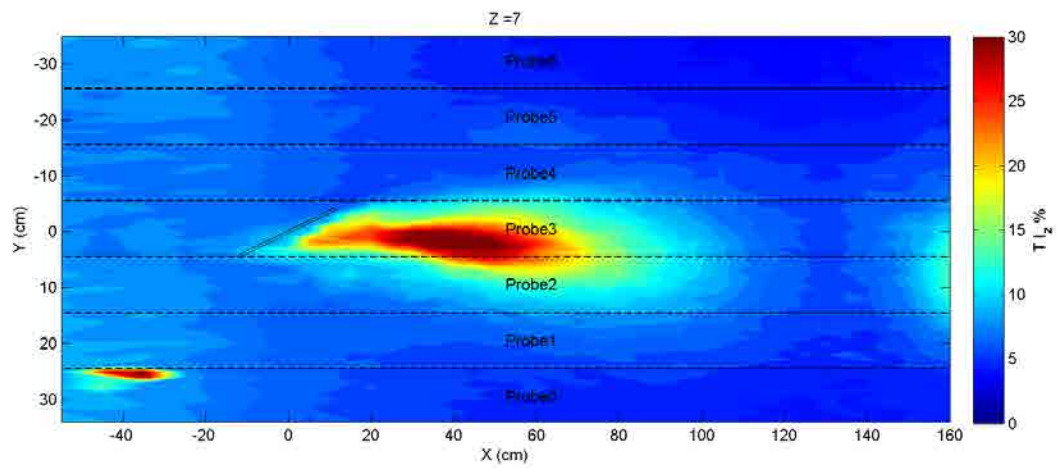


## Turbulence Intensity $T.I_z$ in x and y-Directions

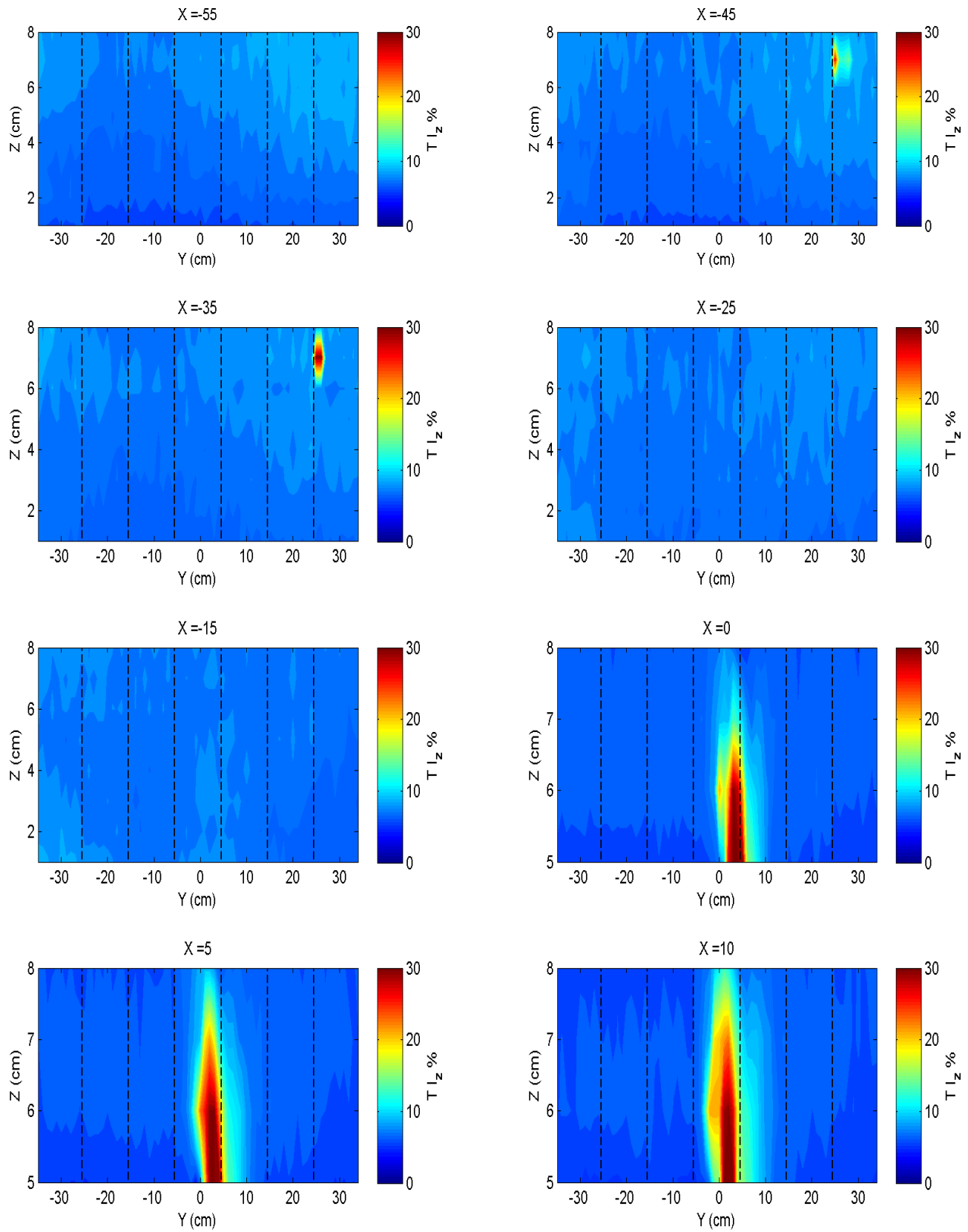


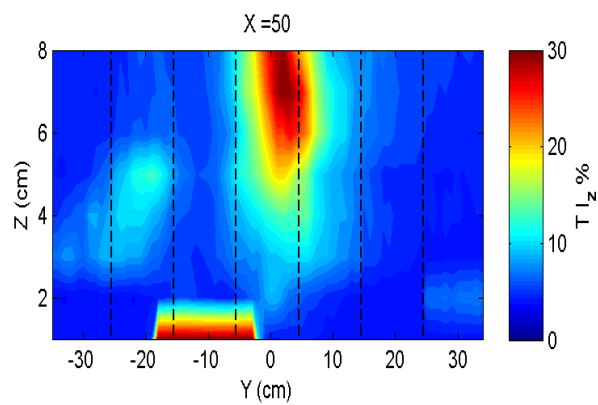
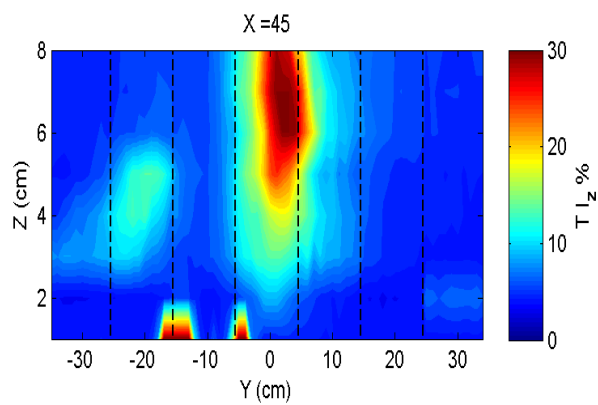
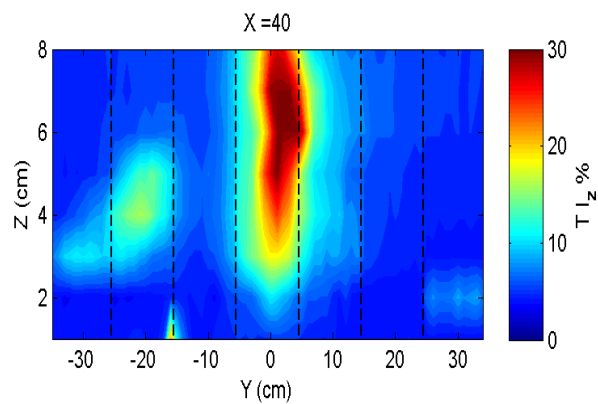
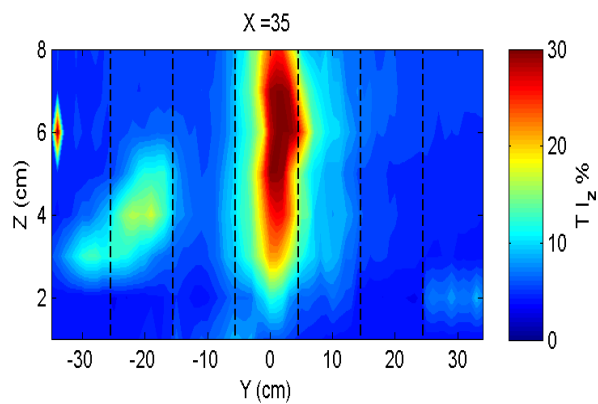
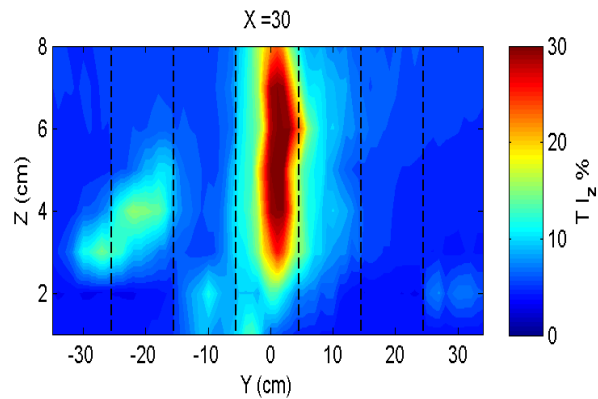
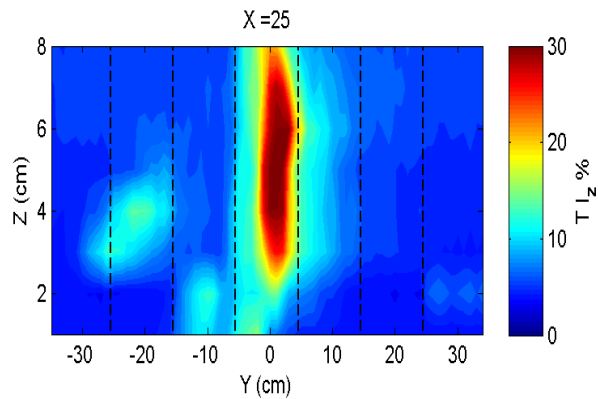
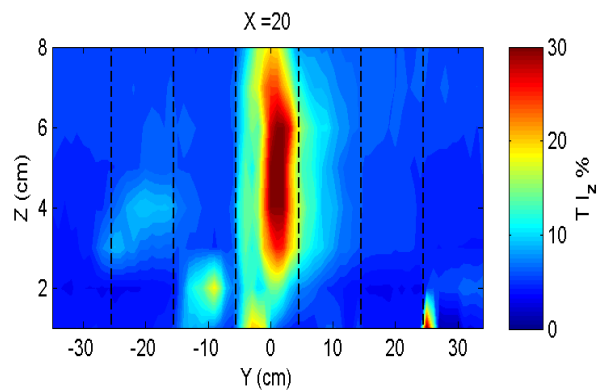
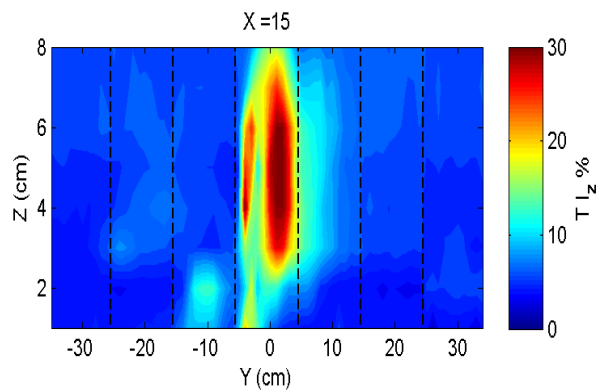


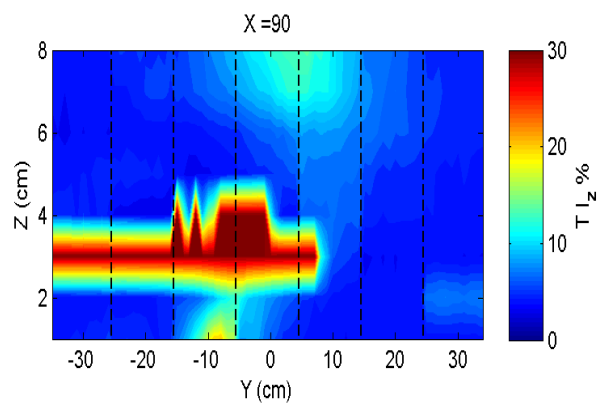
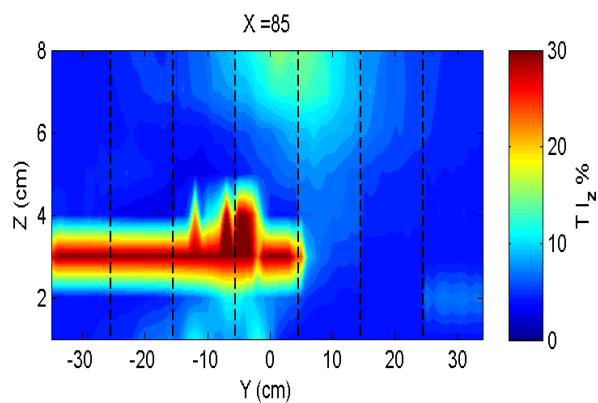
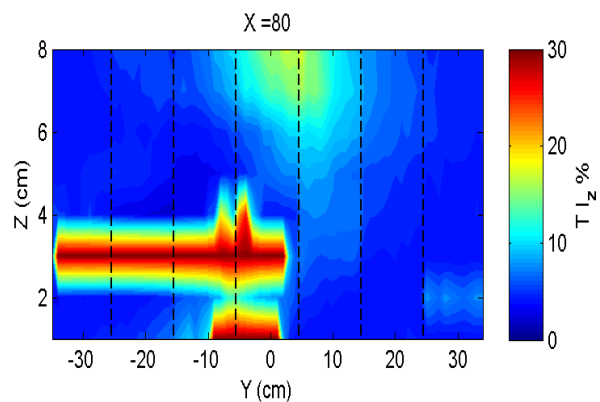
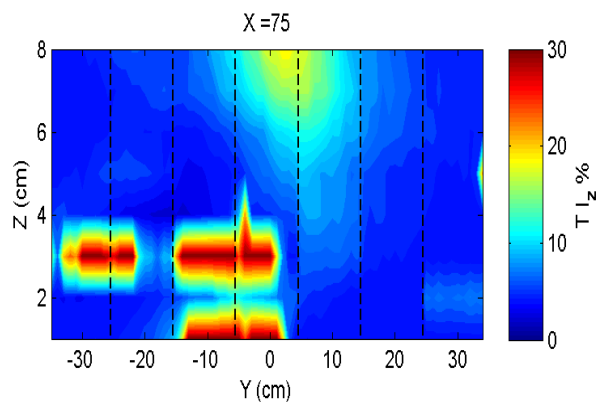
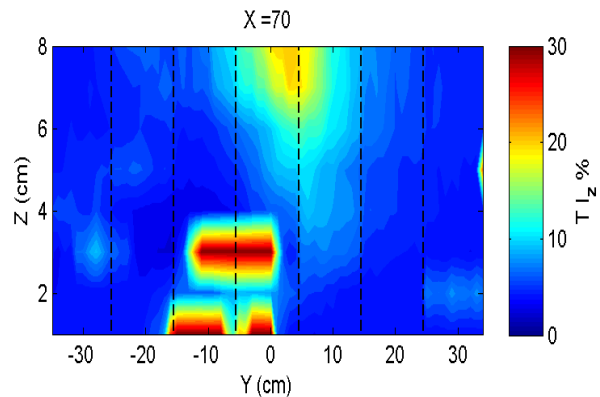
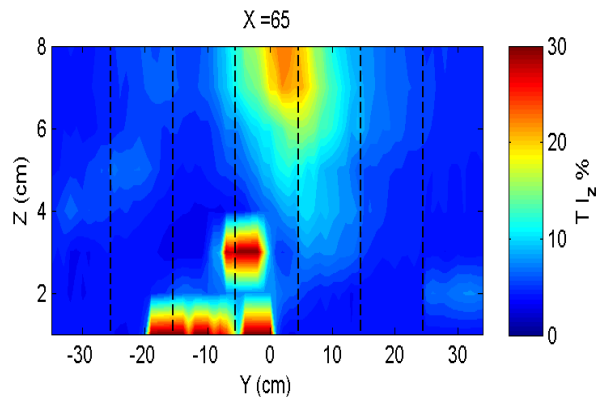
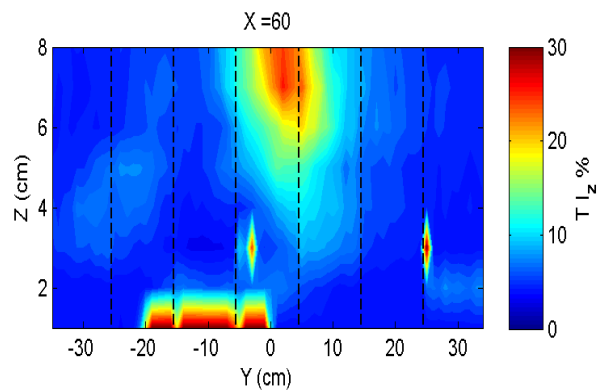
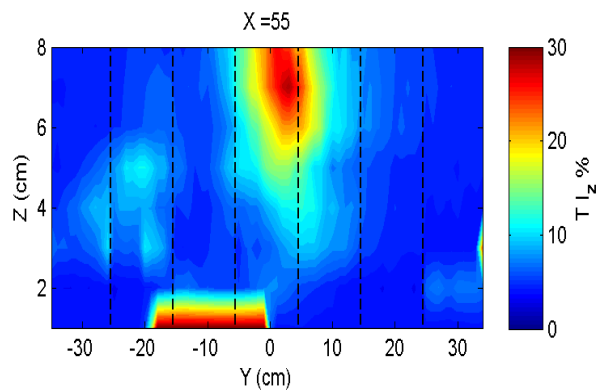


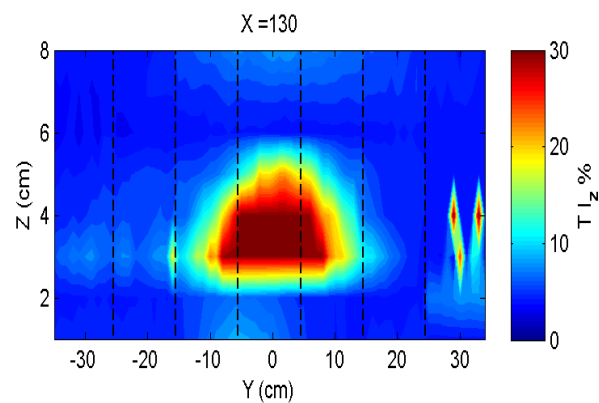
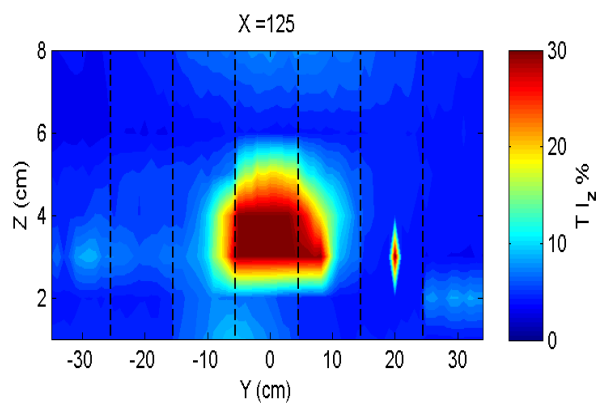
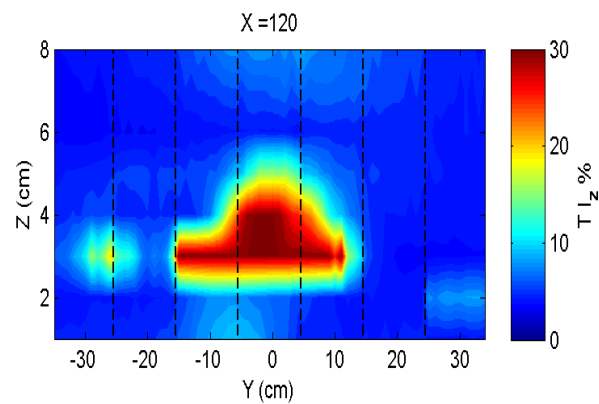
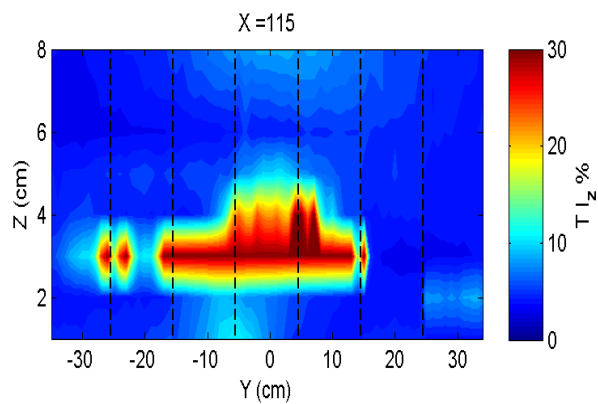
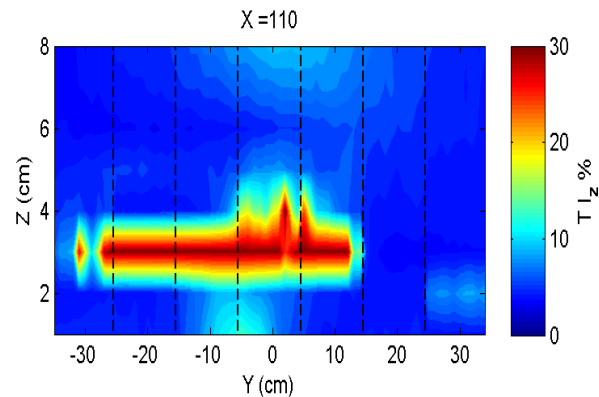
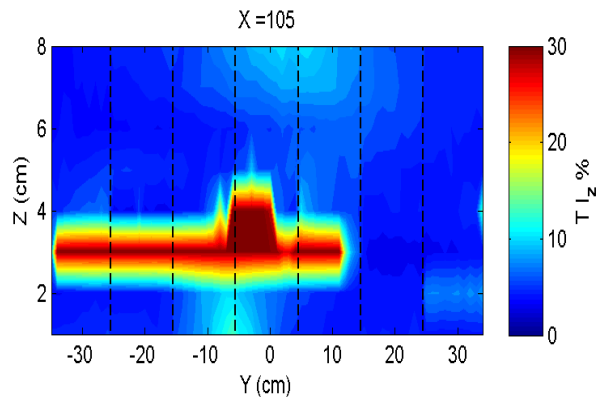
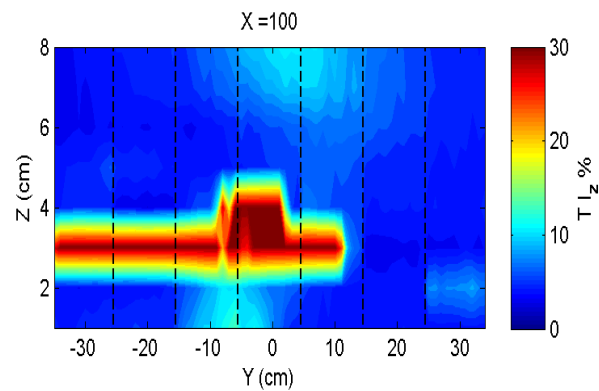
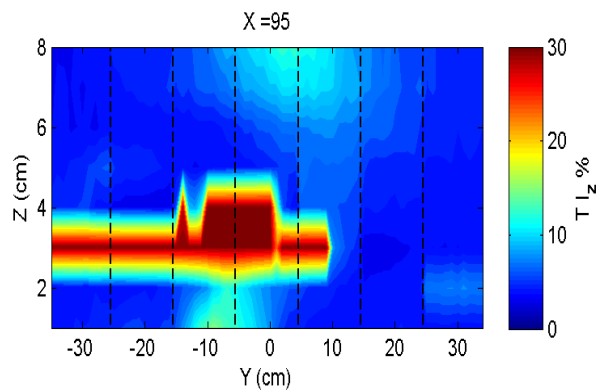


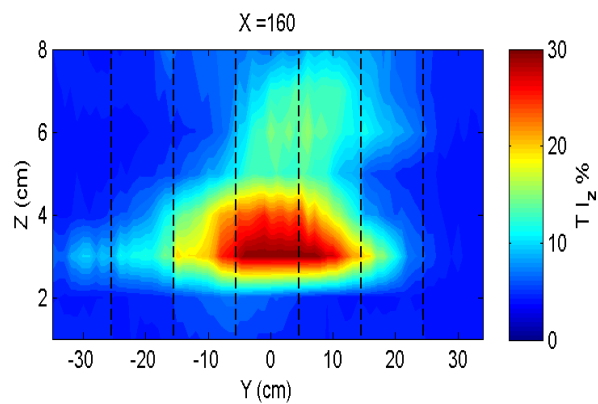
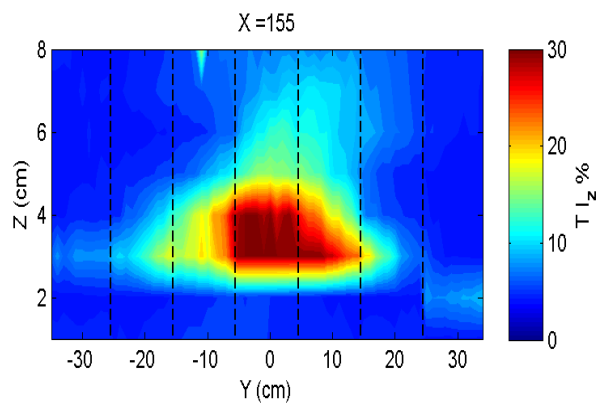
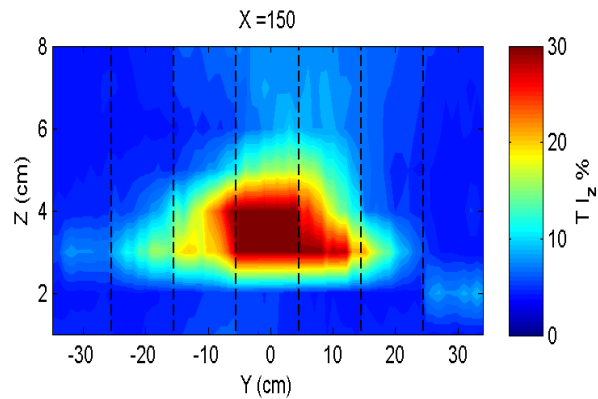
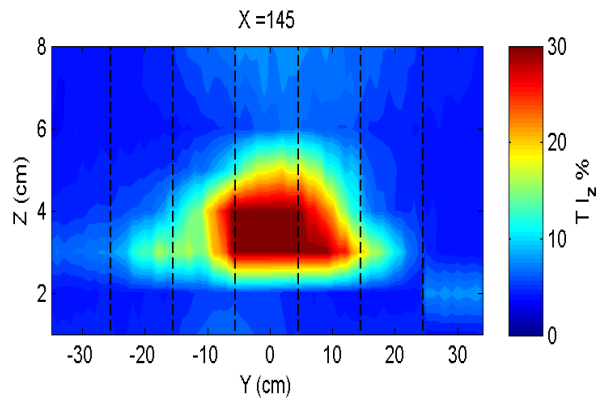
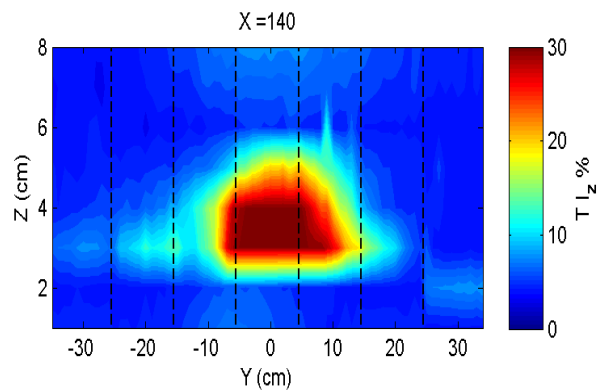
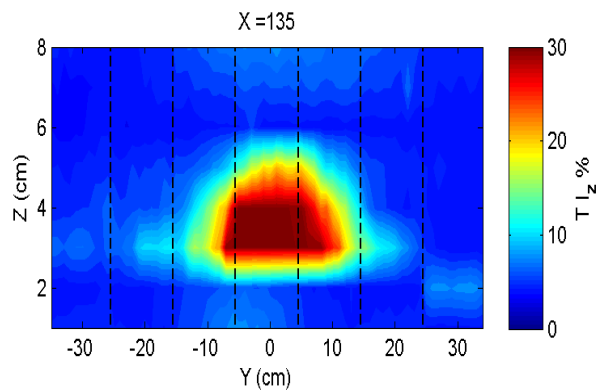
## Turbulence Intensity $T.I_z$ in y and z-Directions



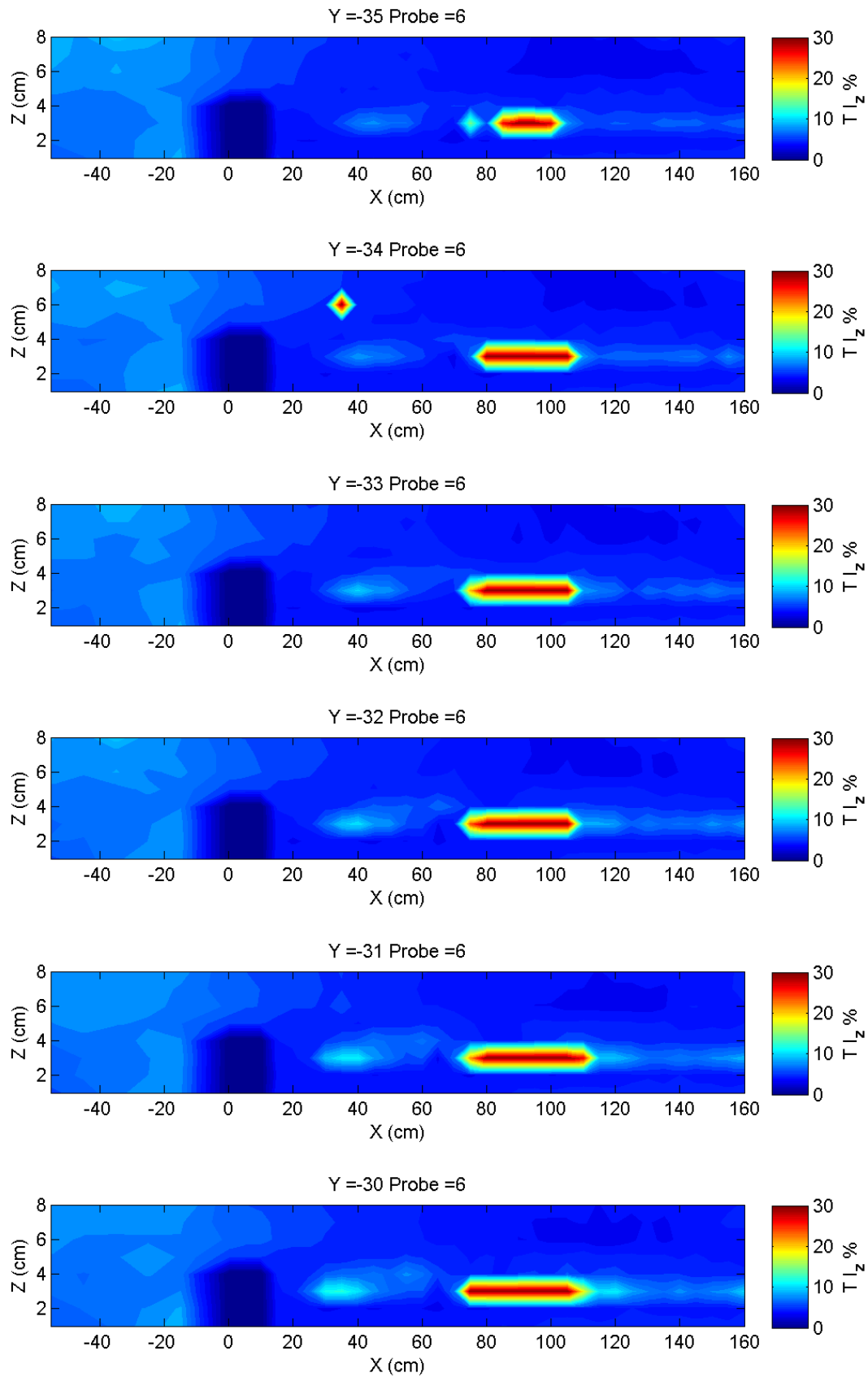




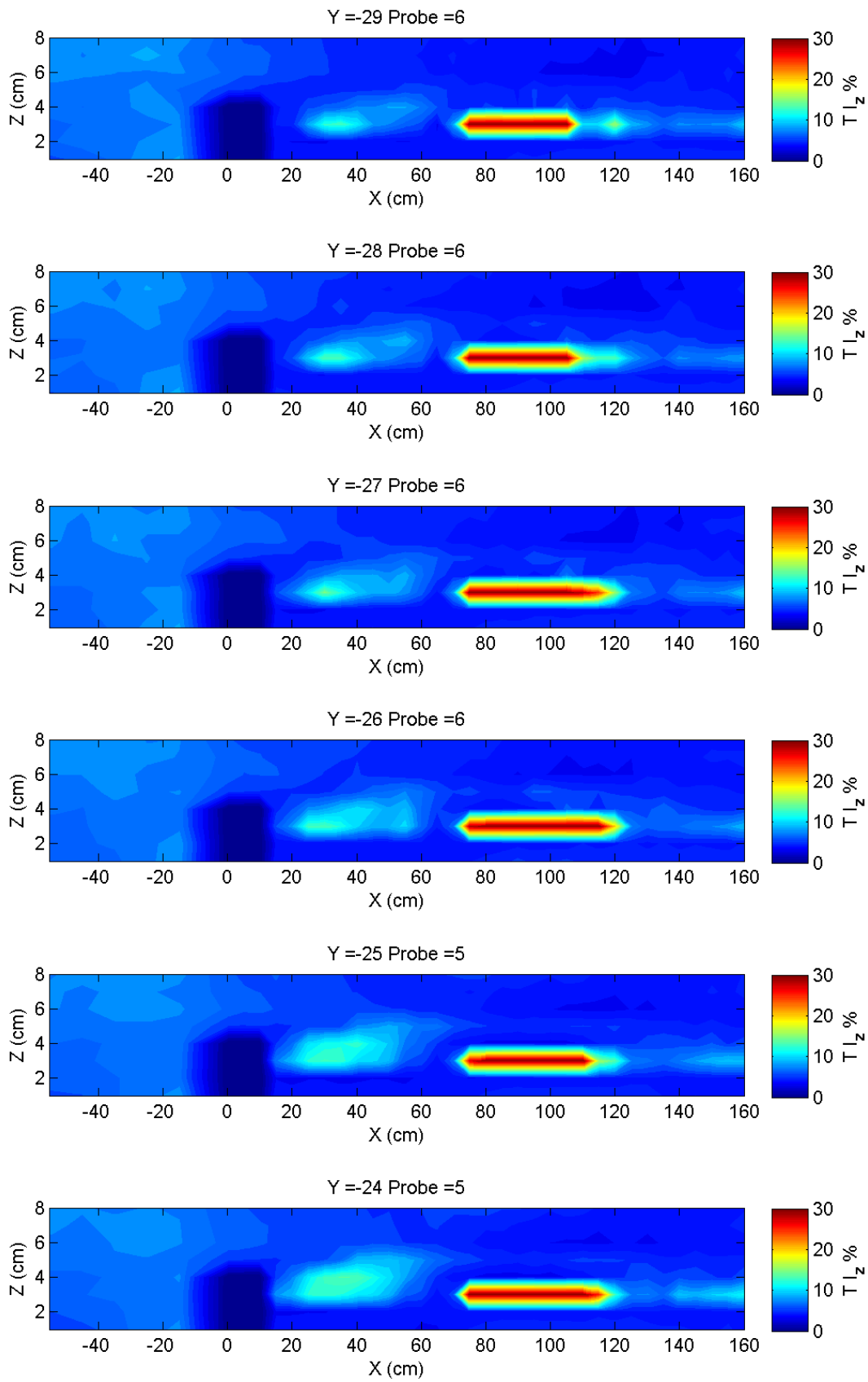


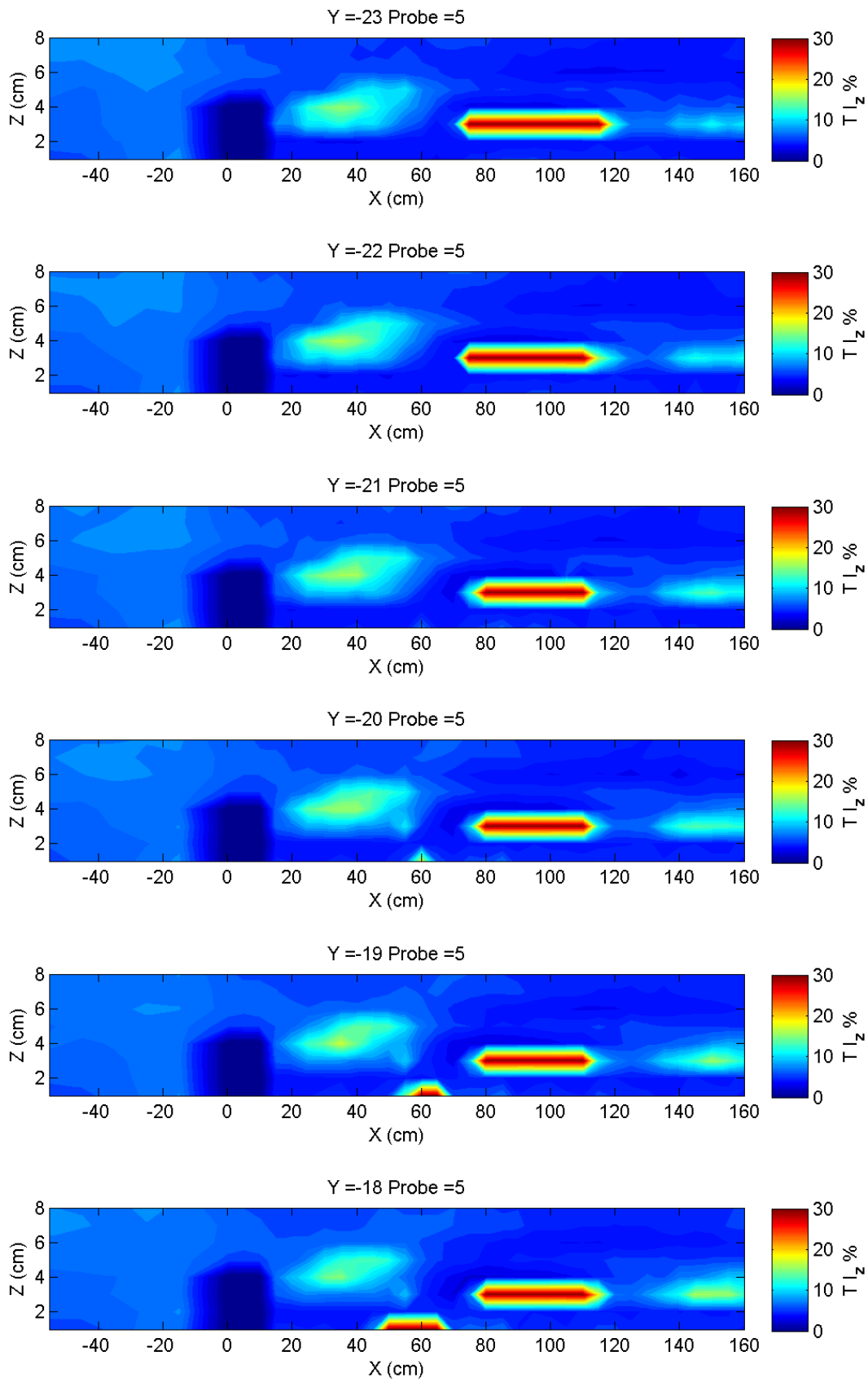


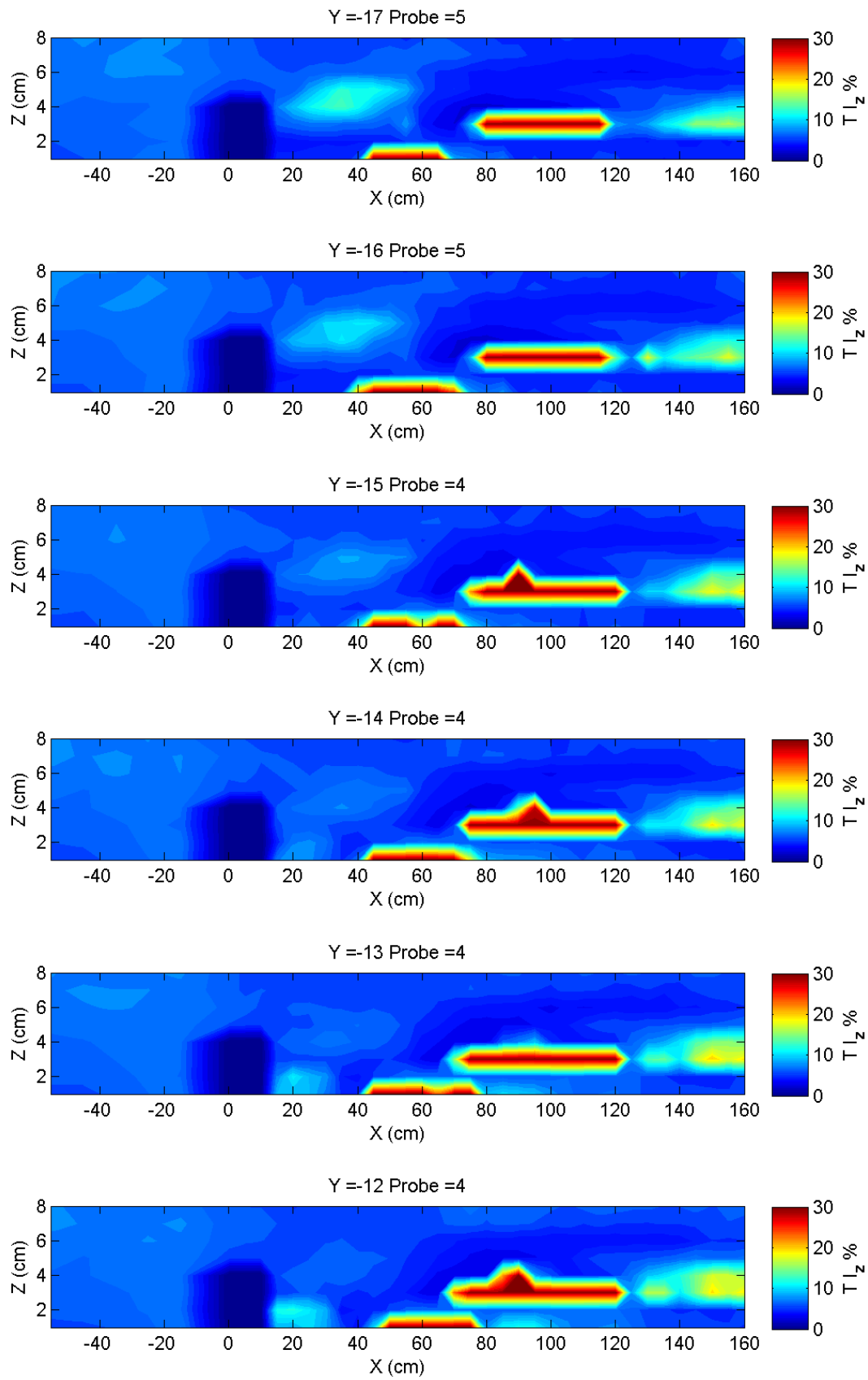
## Turbulence Intensity $T.I_z$ in x and z-Directions

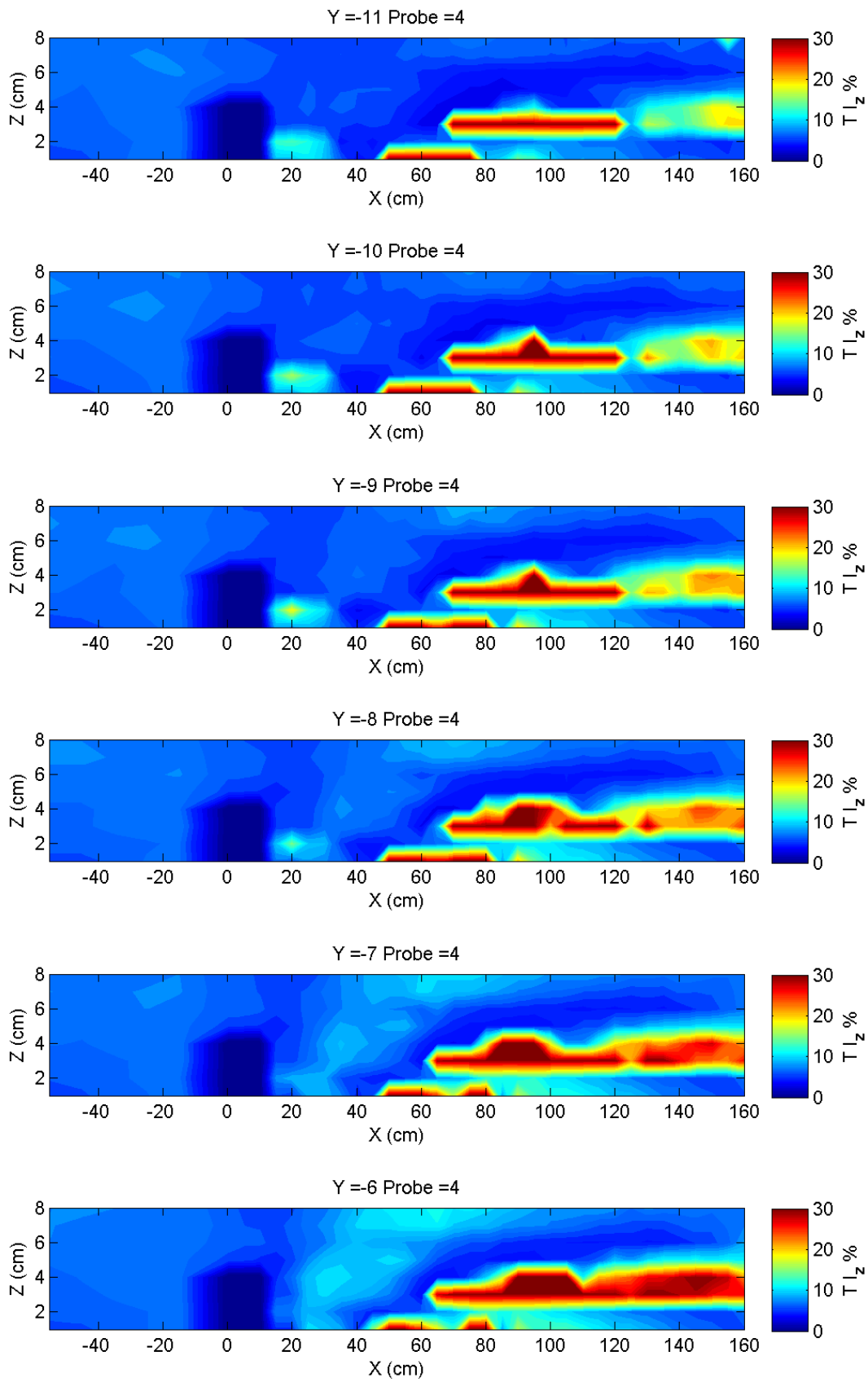


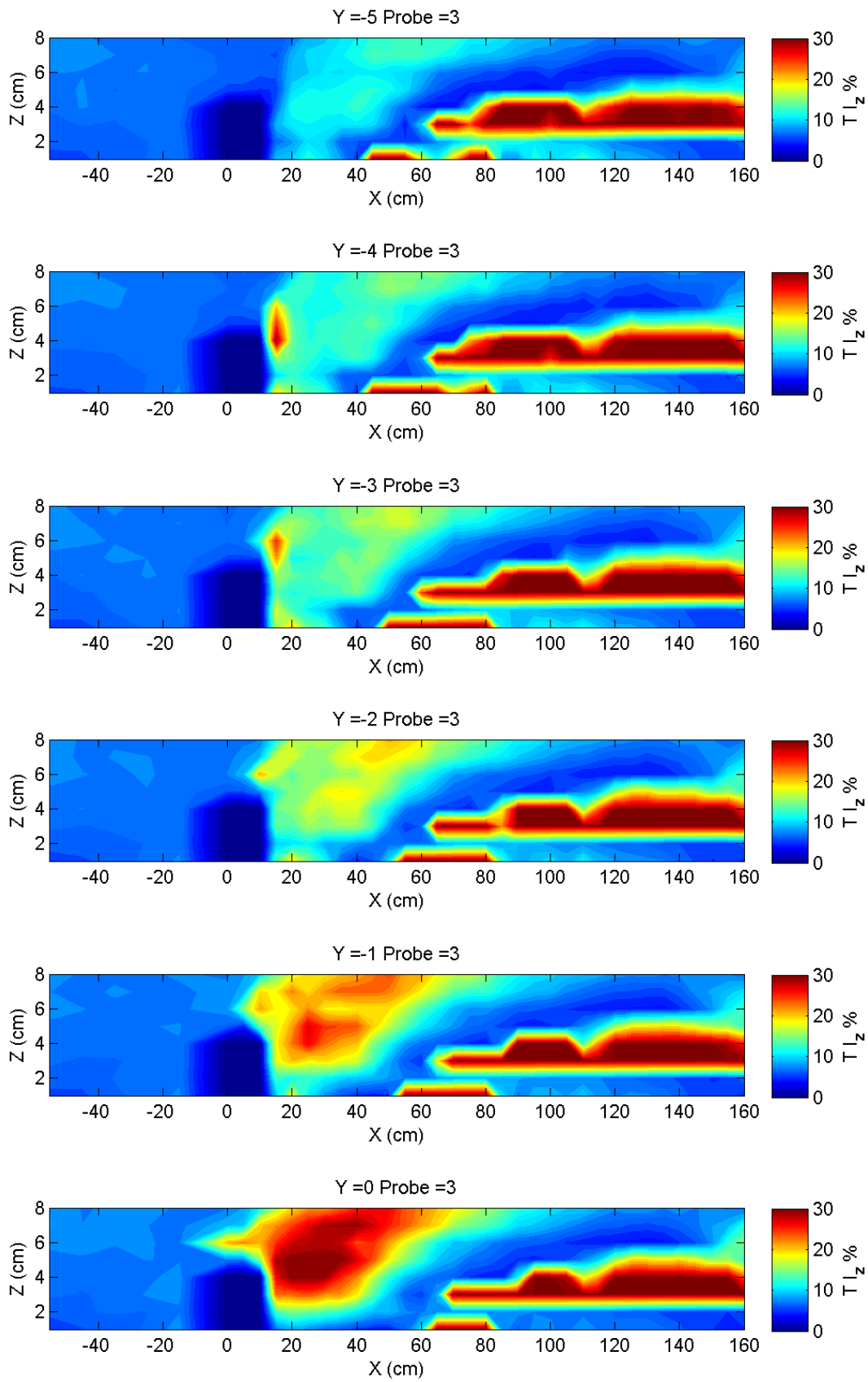


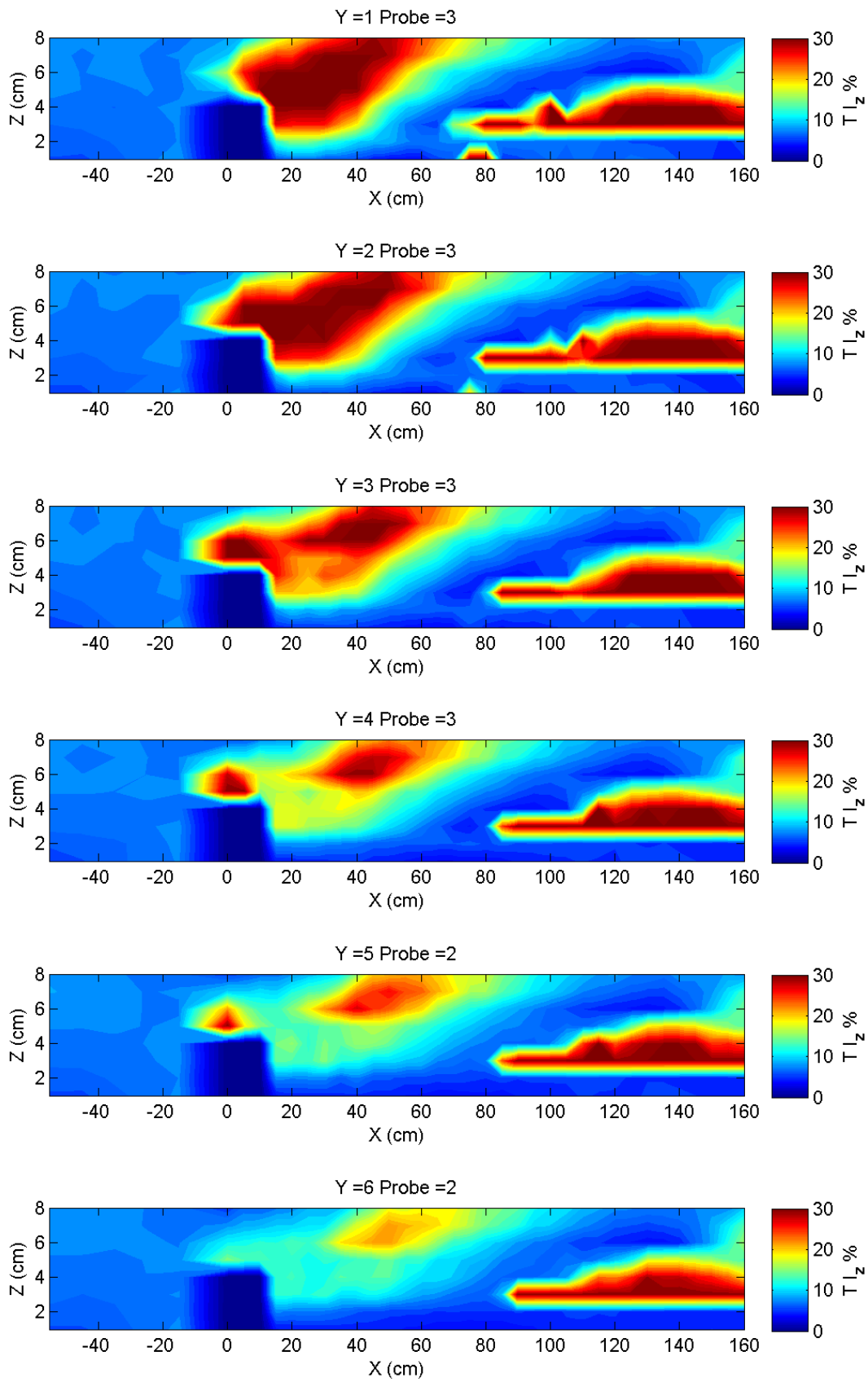


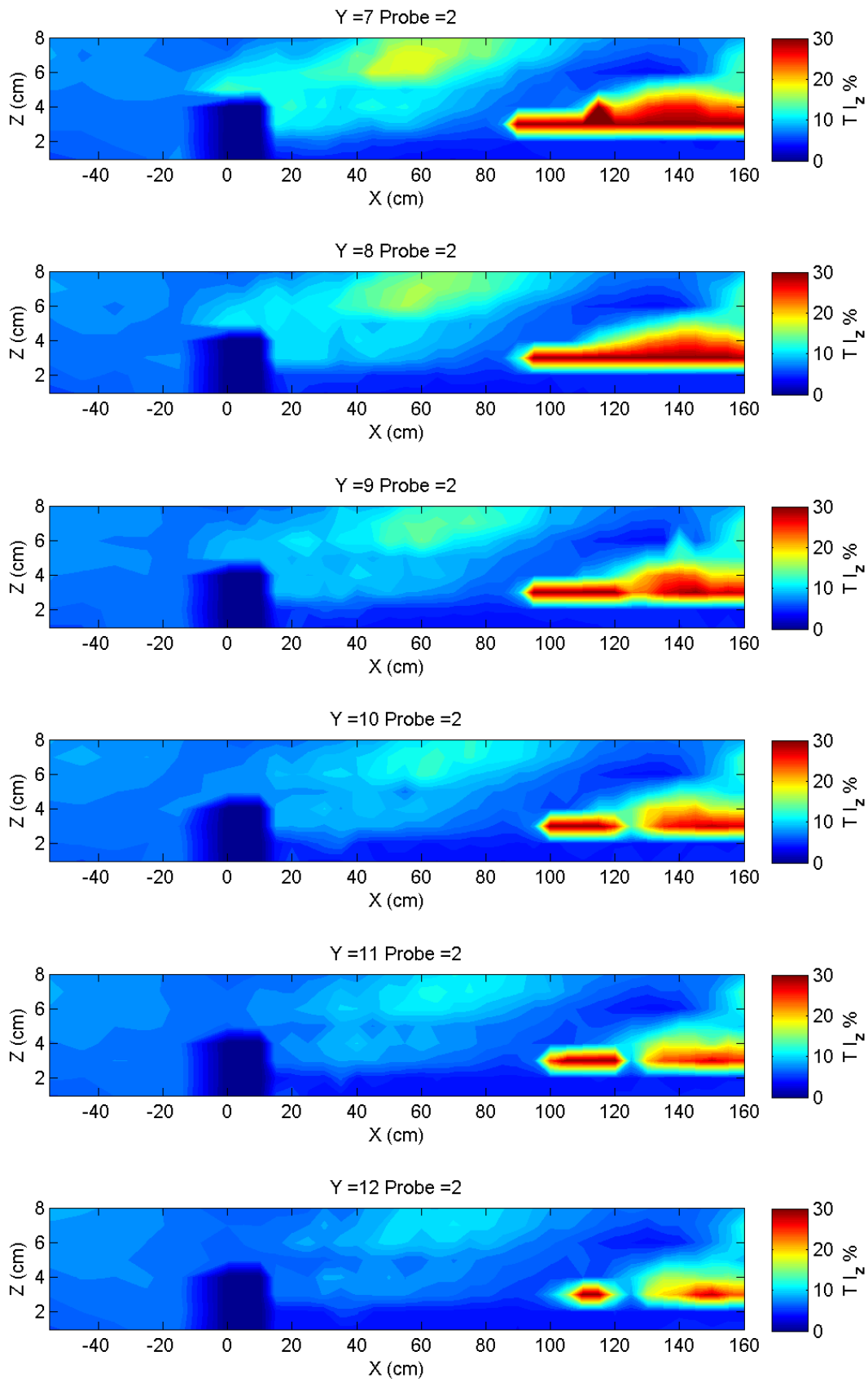


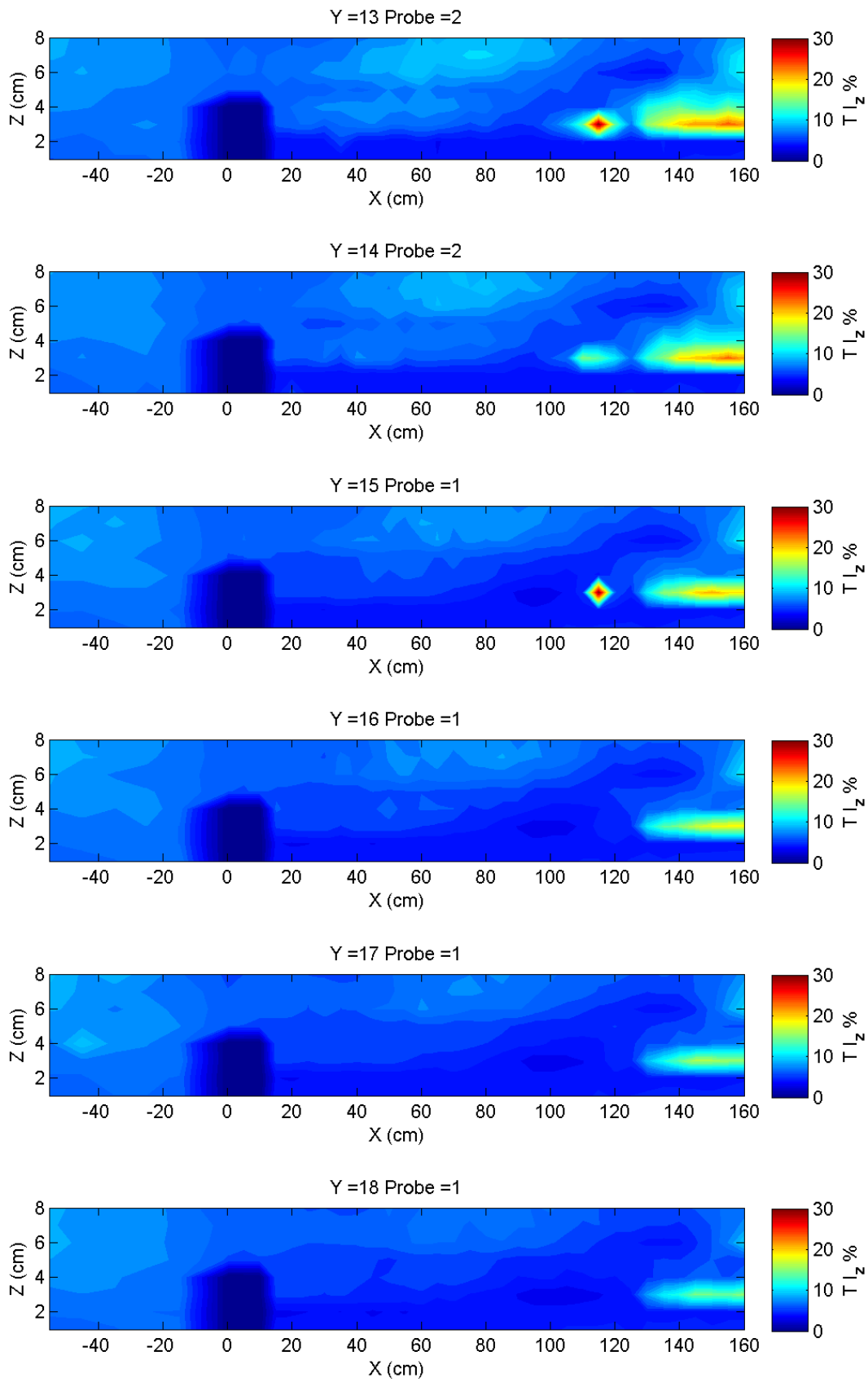




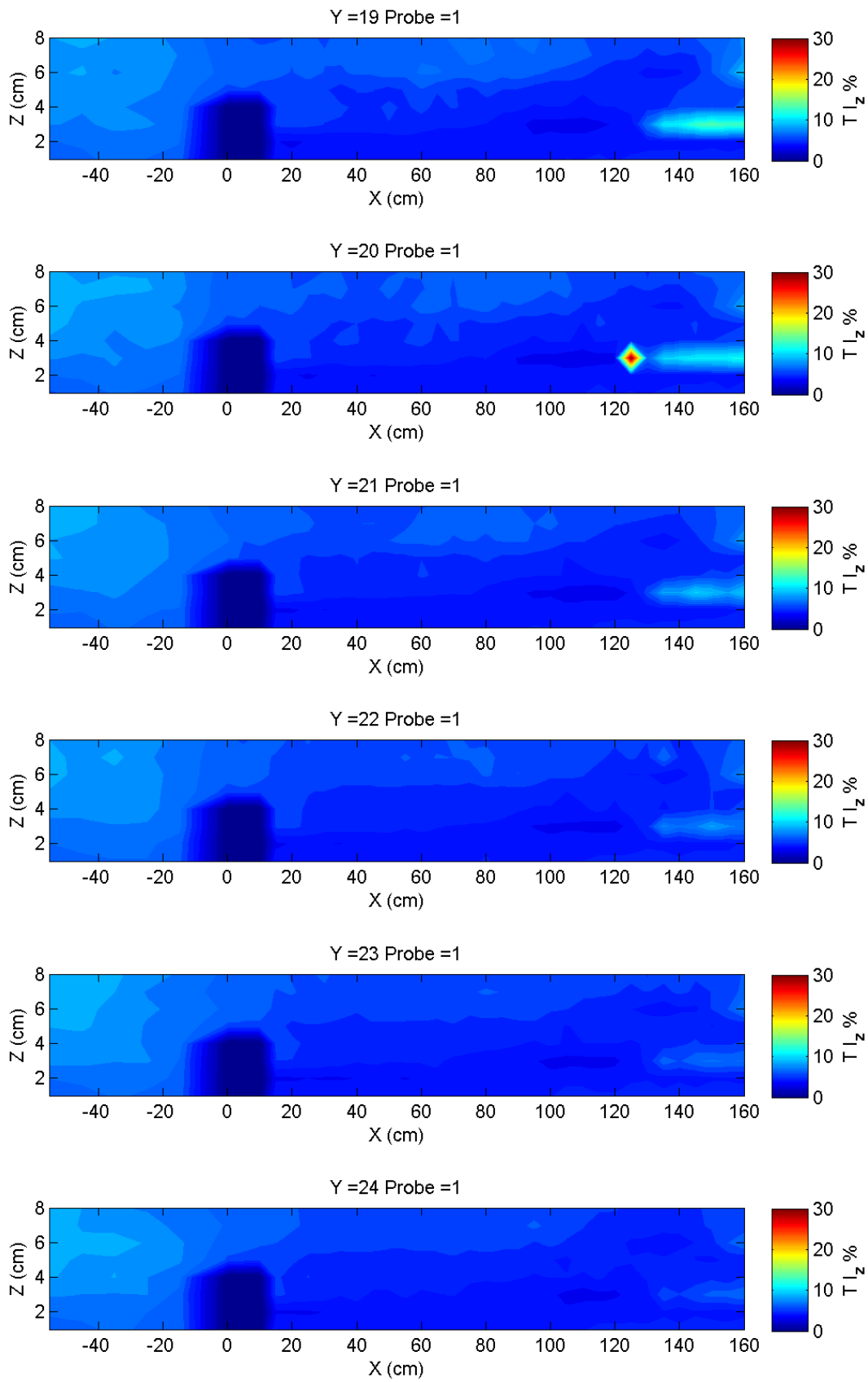


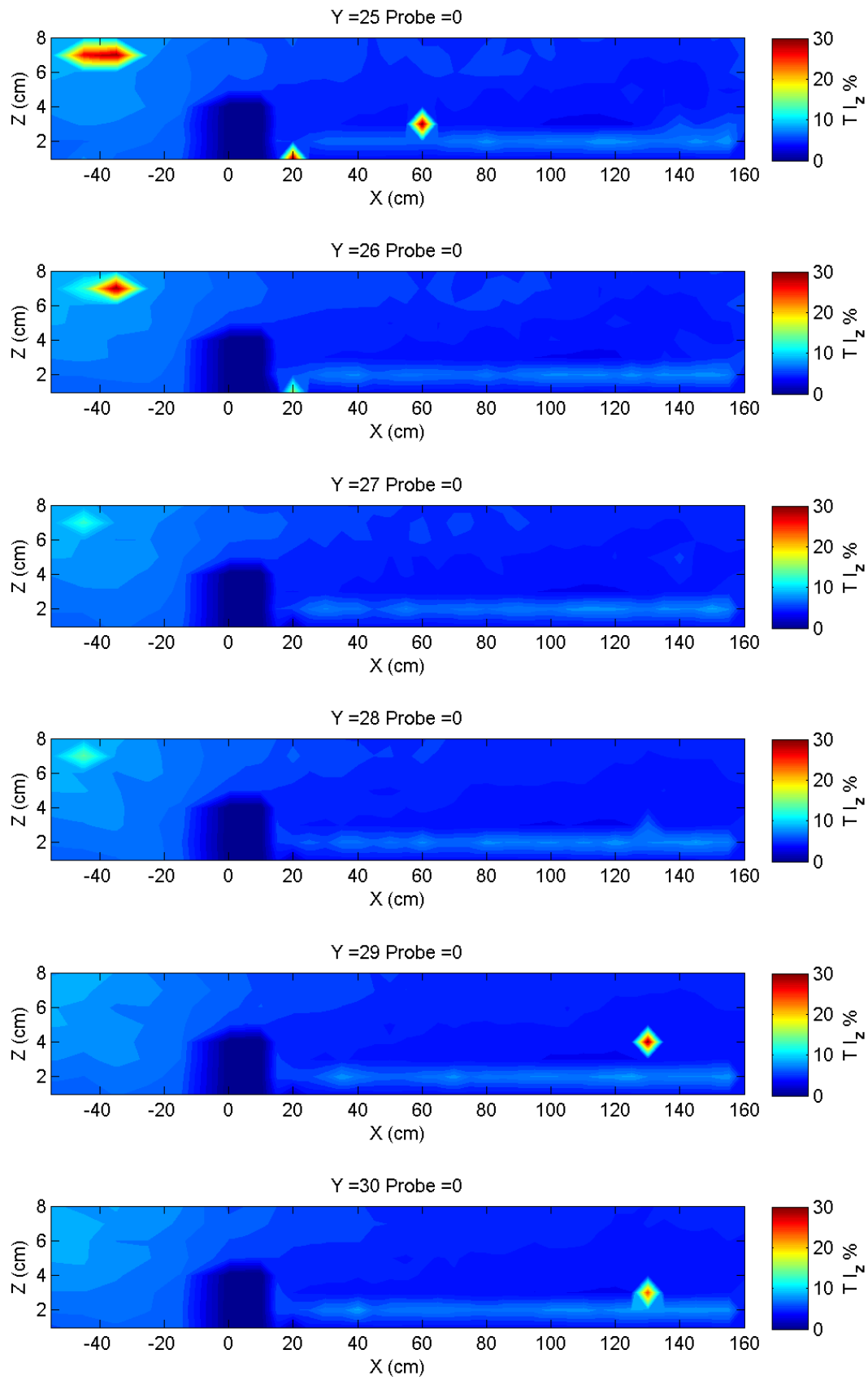


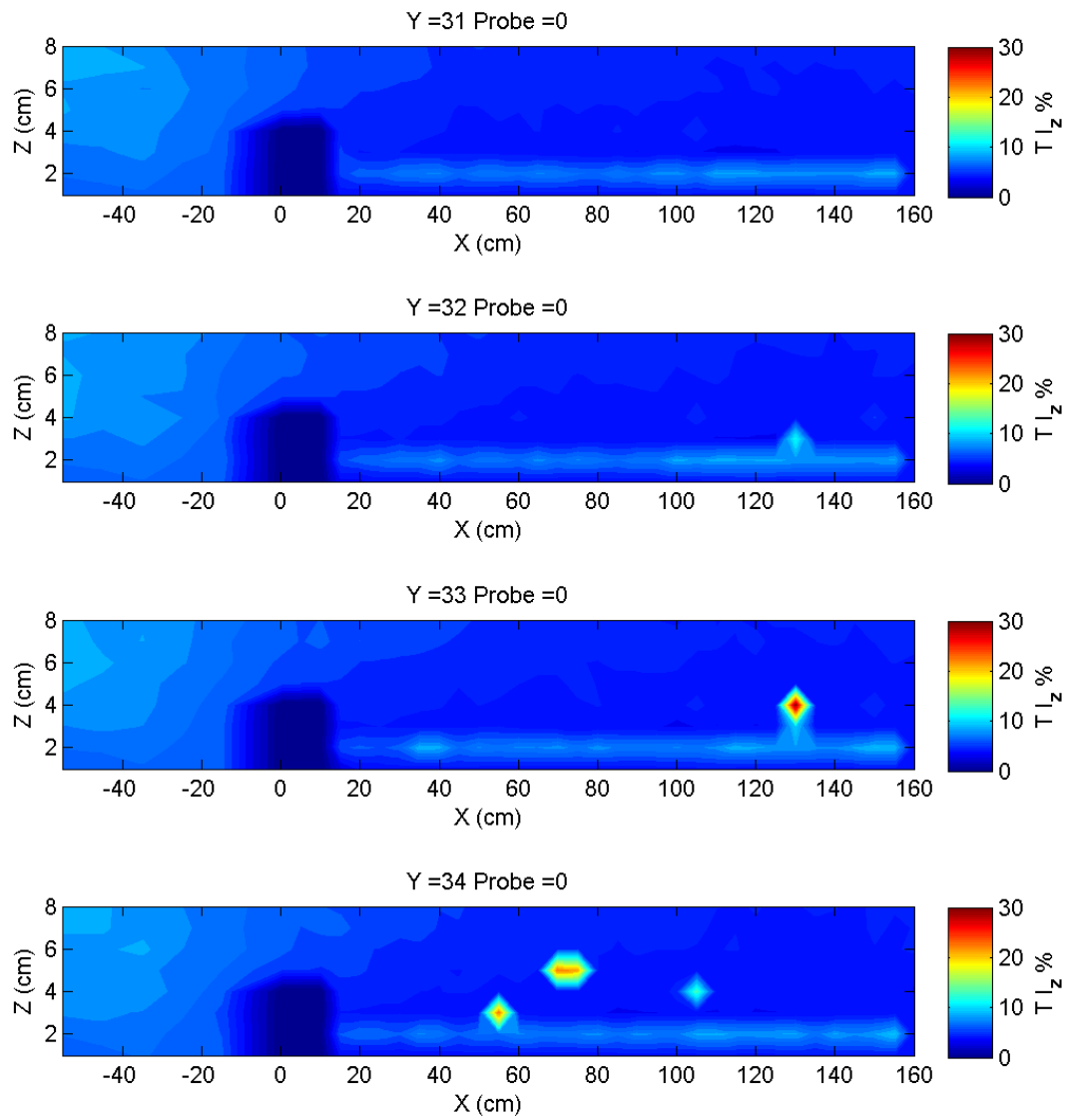










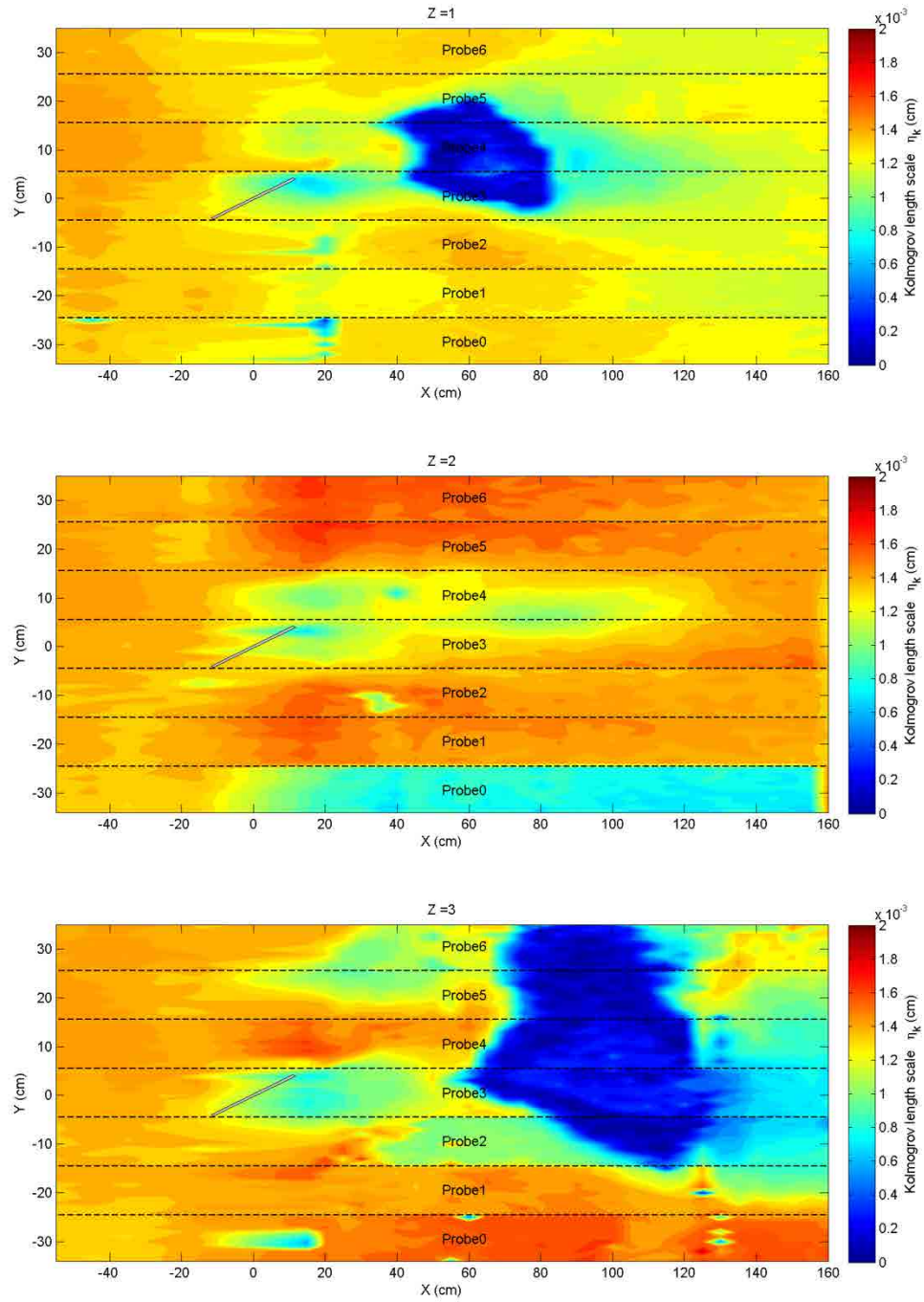


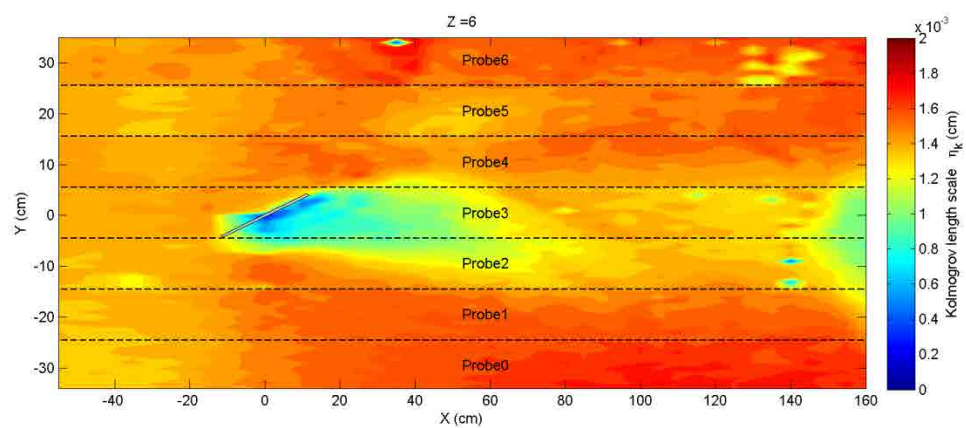
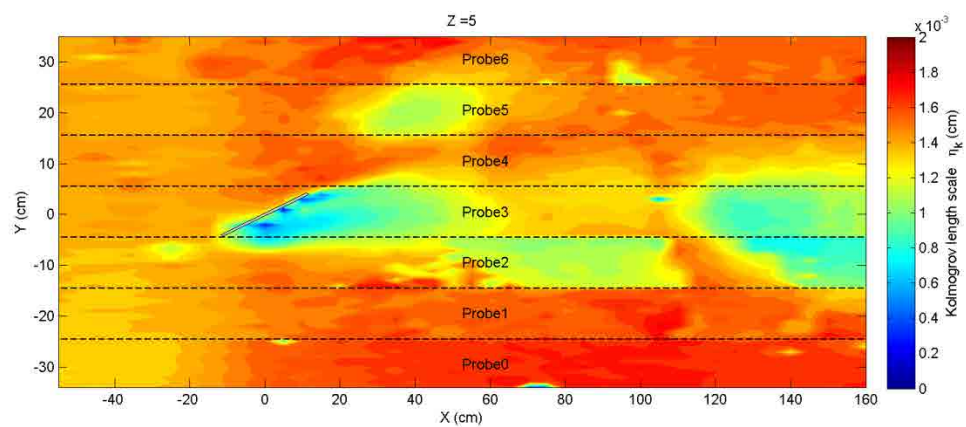
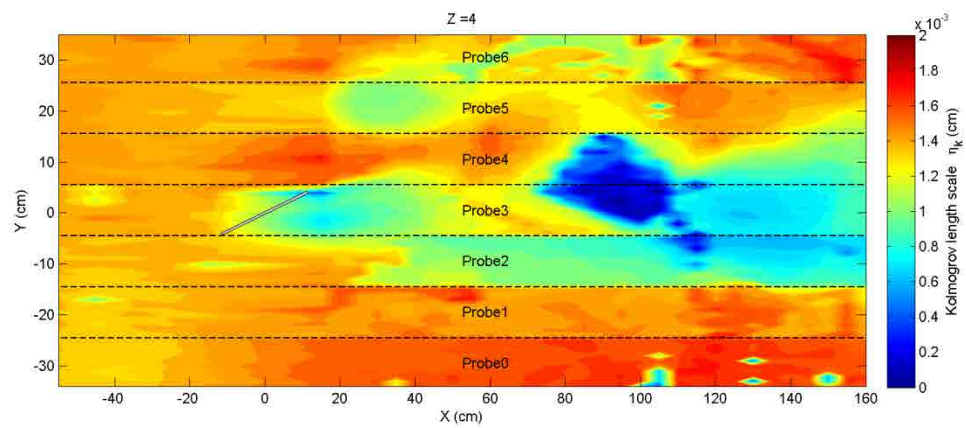
## Appendix C Results – Submerged Vanes Turbulence Statistics

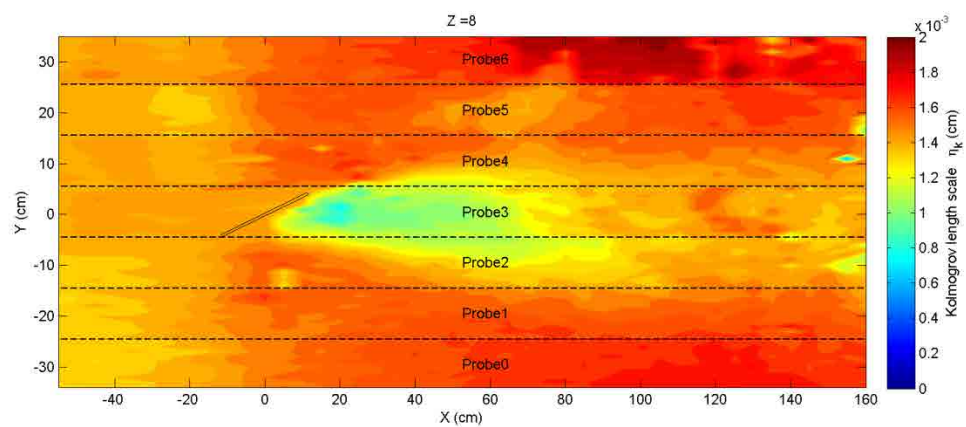
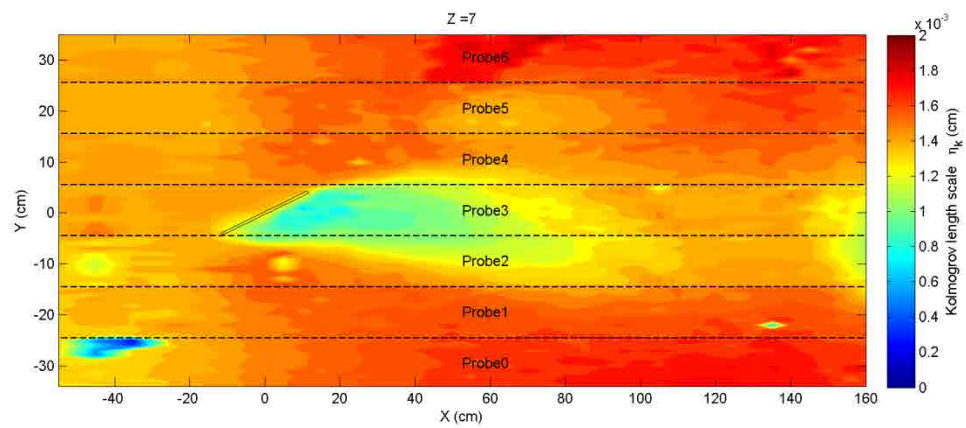
### C.5 Kolmogorov Scales

#### 1. Kolmogorov Length Scale $\eta_k$

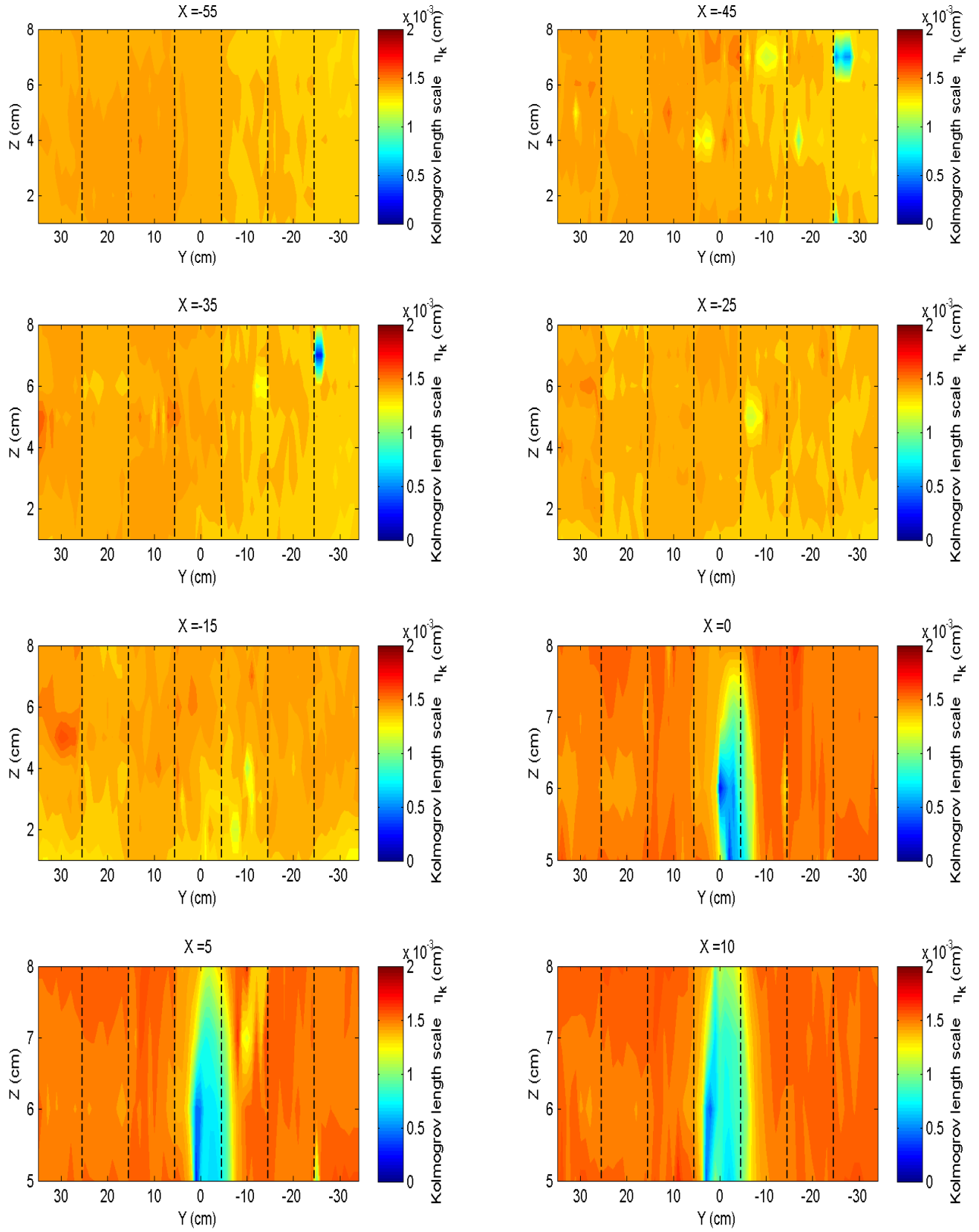
#### Kolmogorov Length Scale $\eta_k$ in x and y-Directions



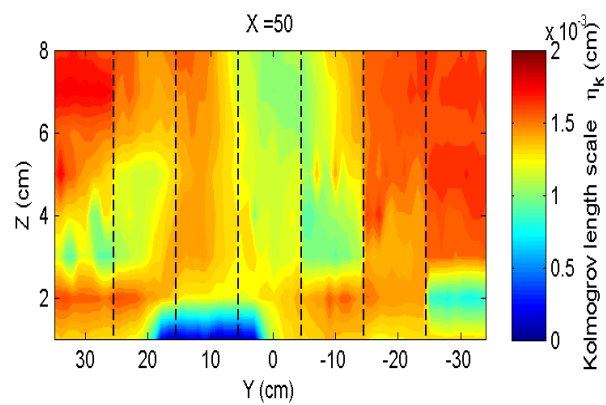
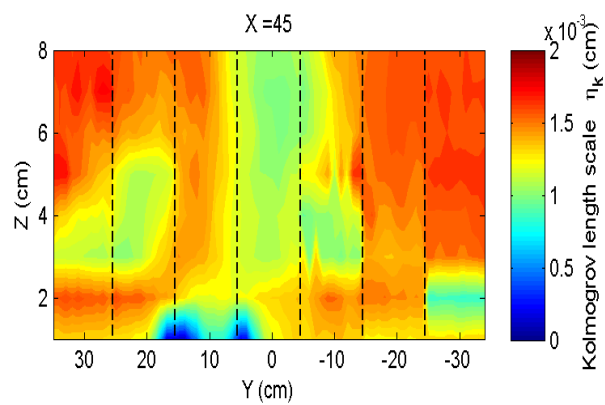
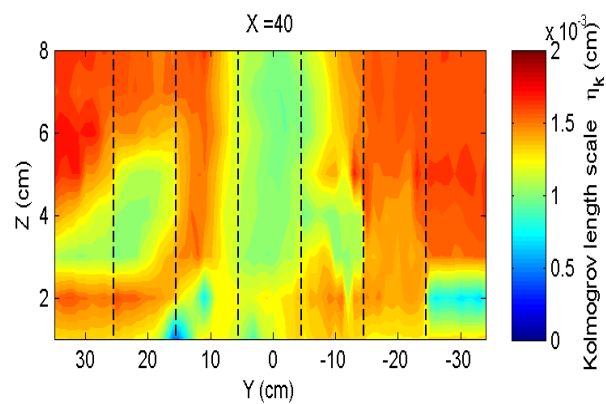
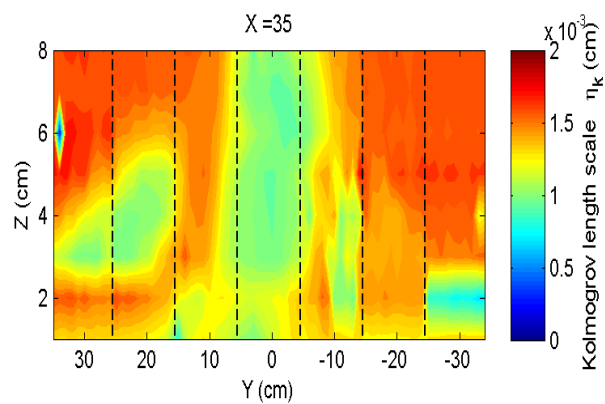
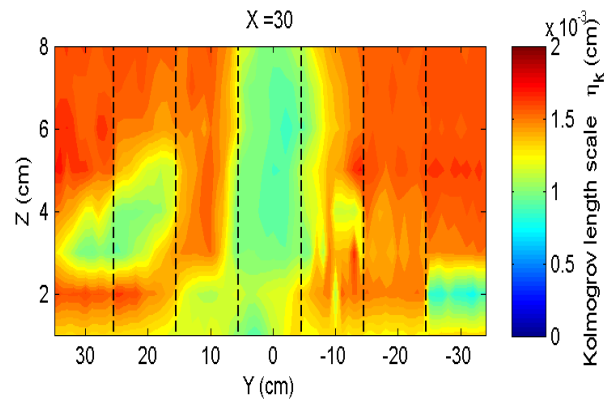
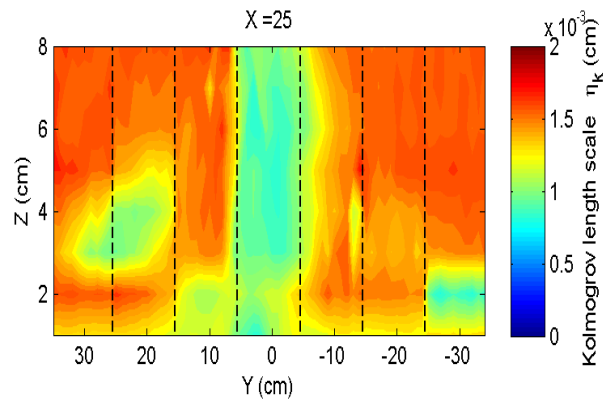
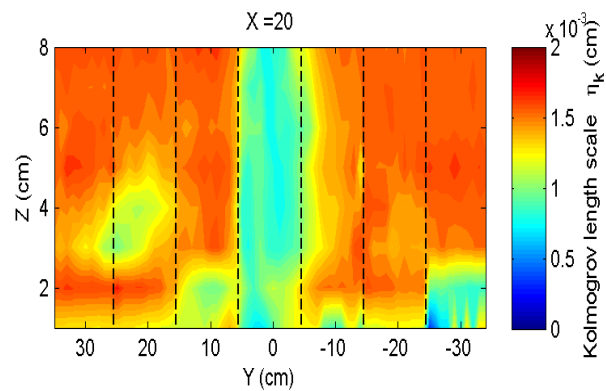
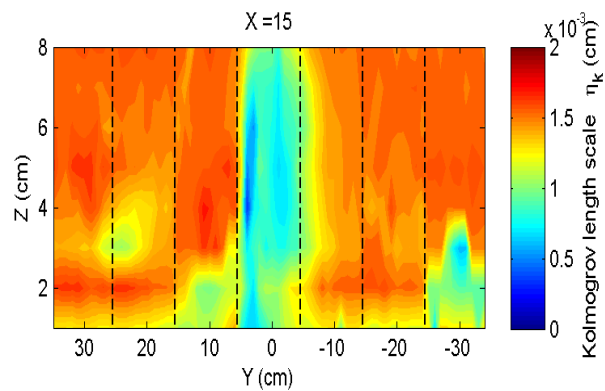




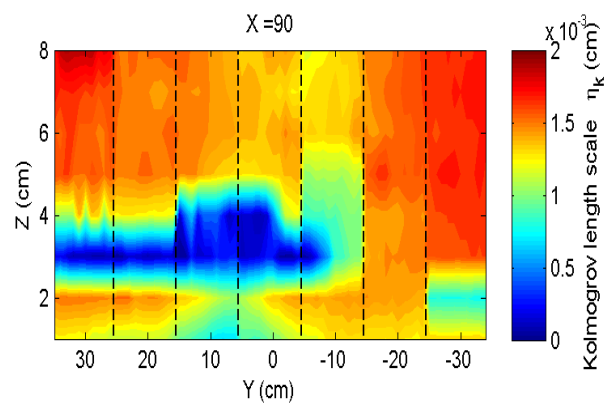
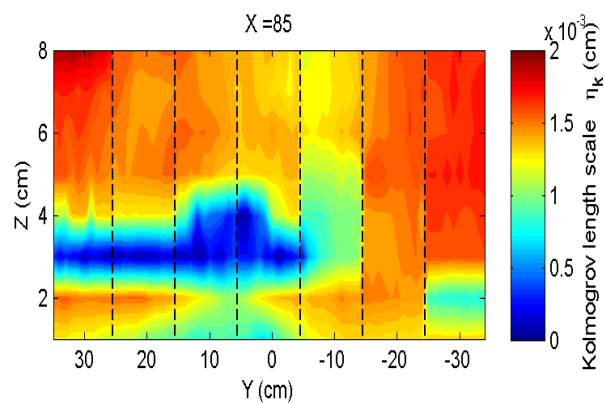
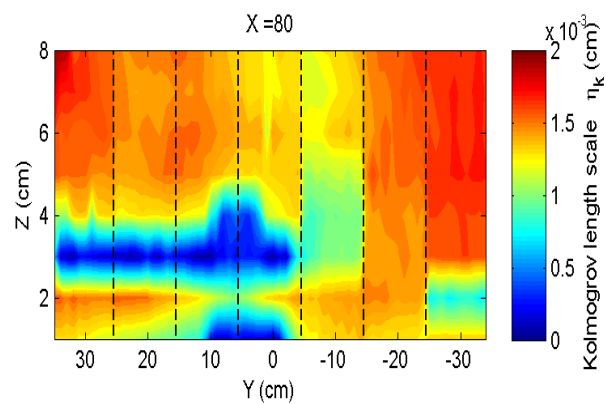
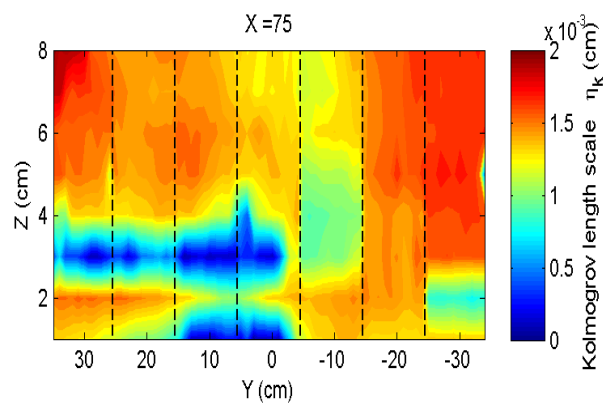
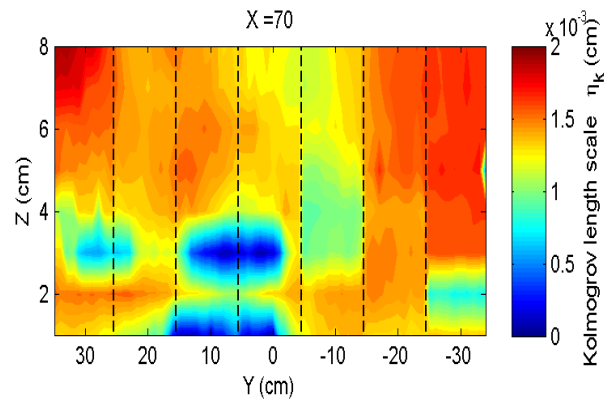
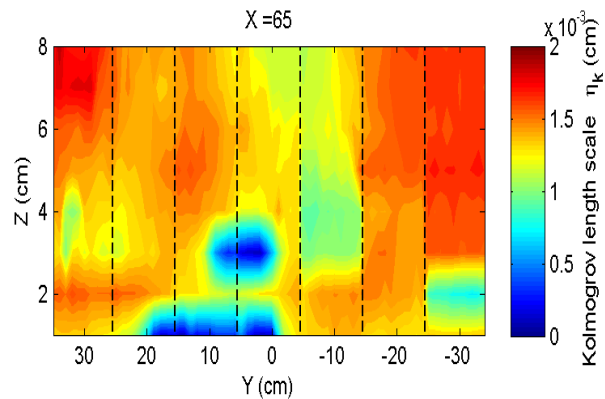
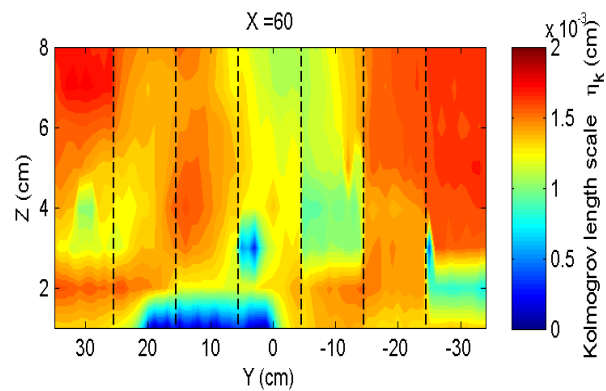
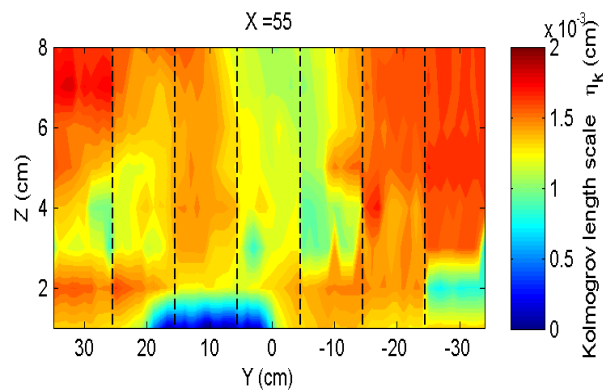
## Kolmogorov Length Scale $\eta_k$ in y and z-Directions

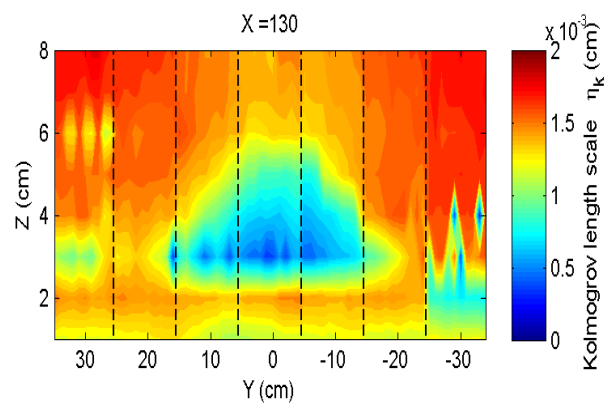
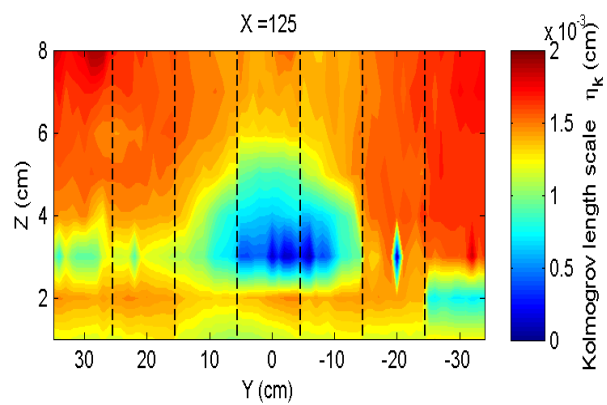
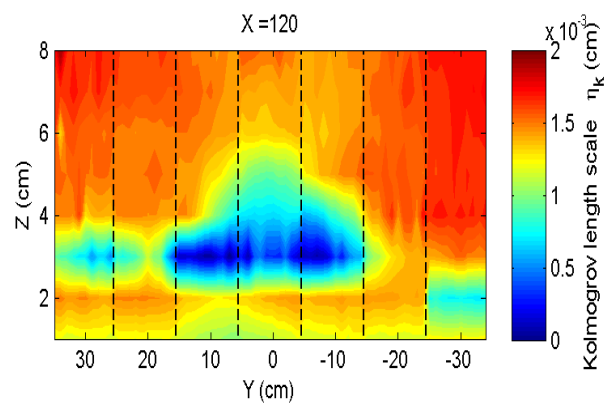
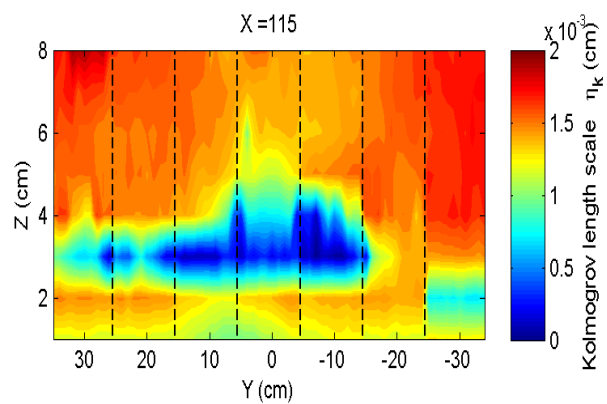
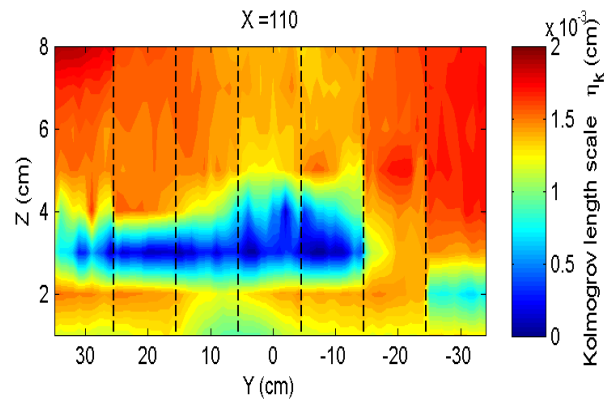
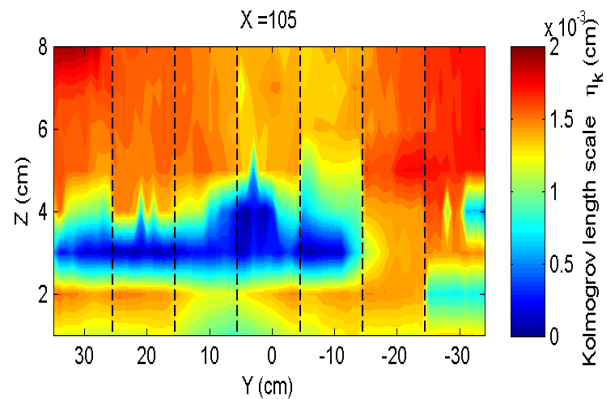
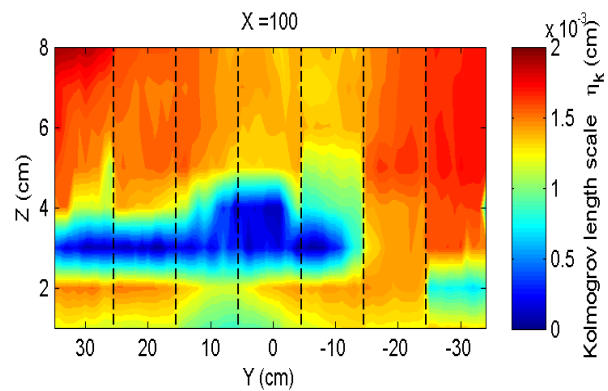
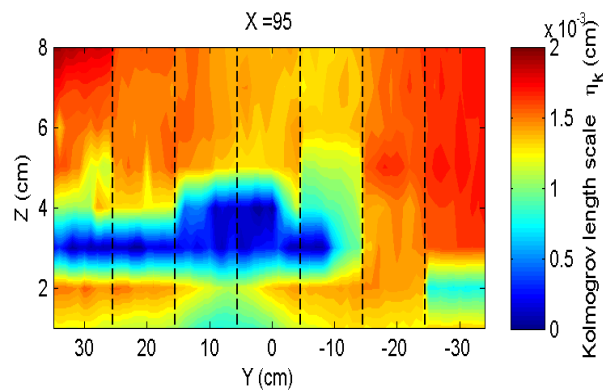


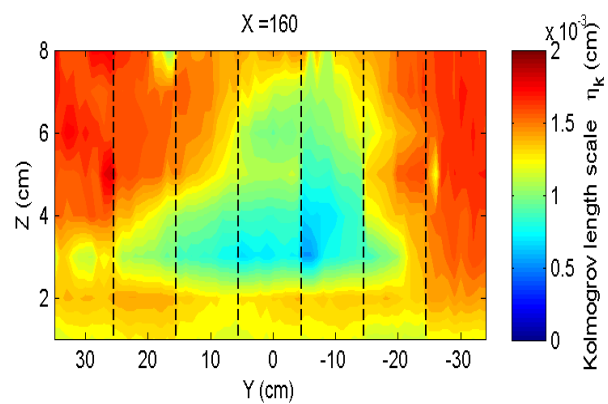
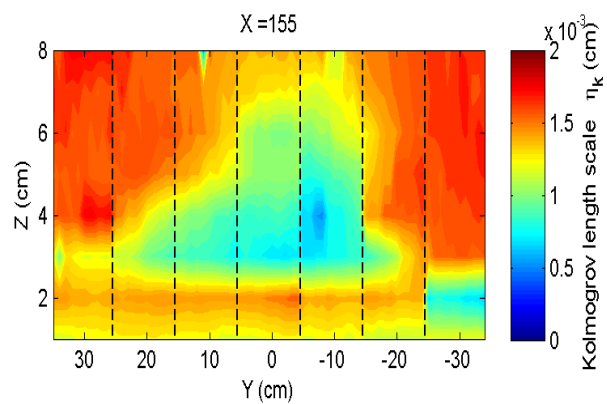
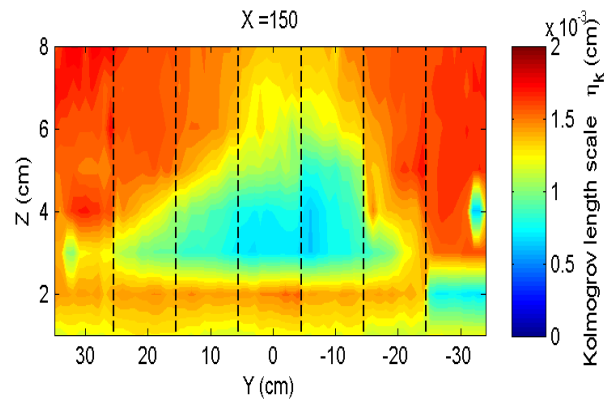
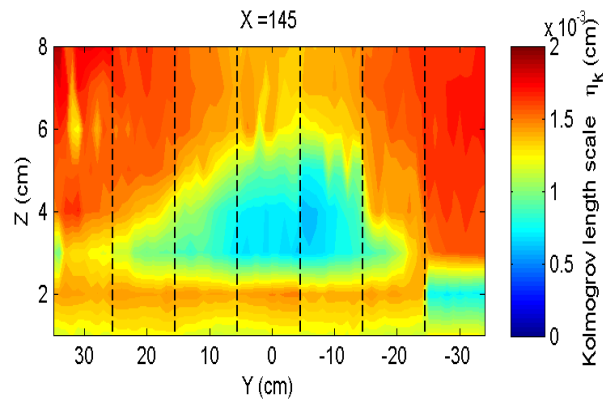
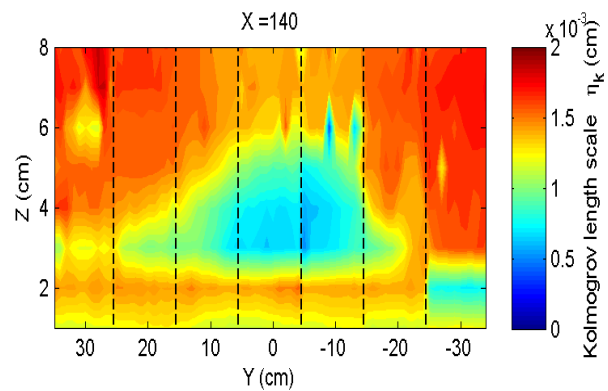
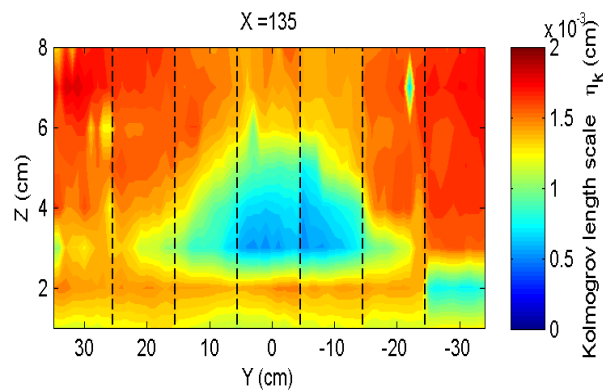




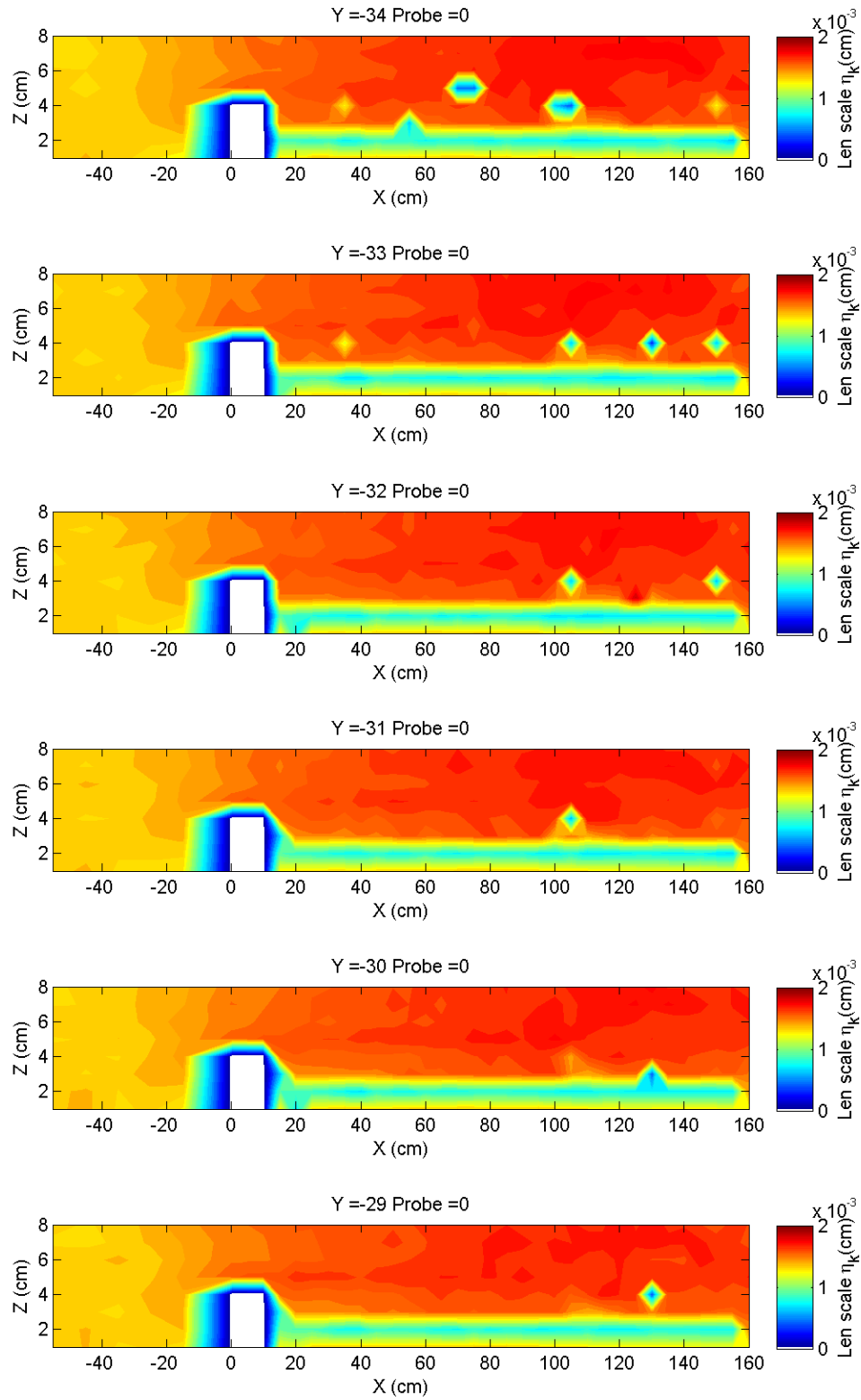


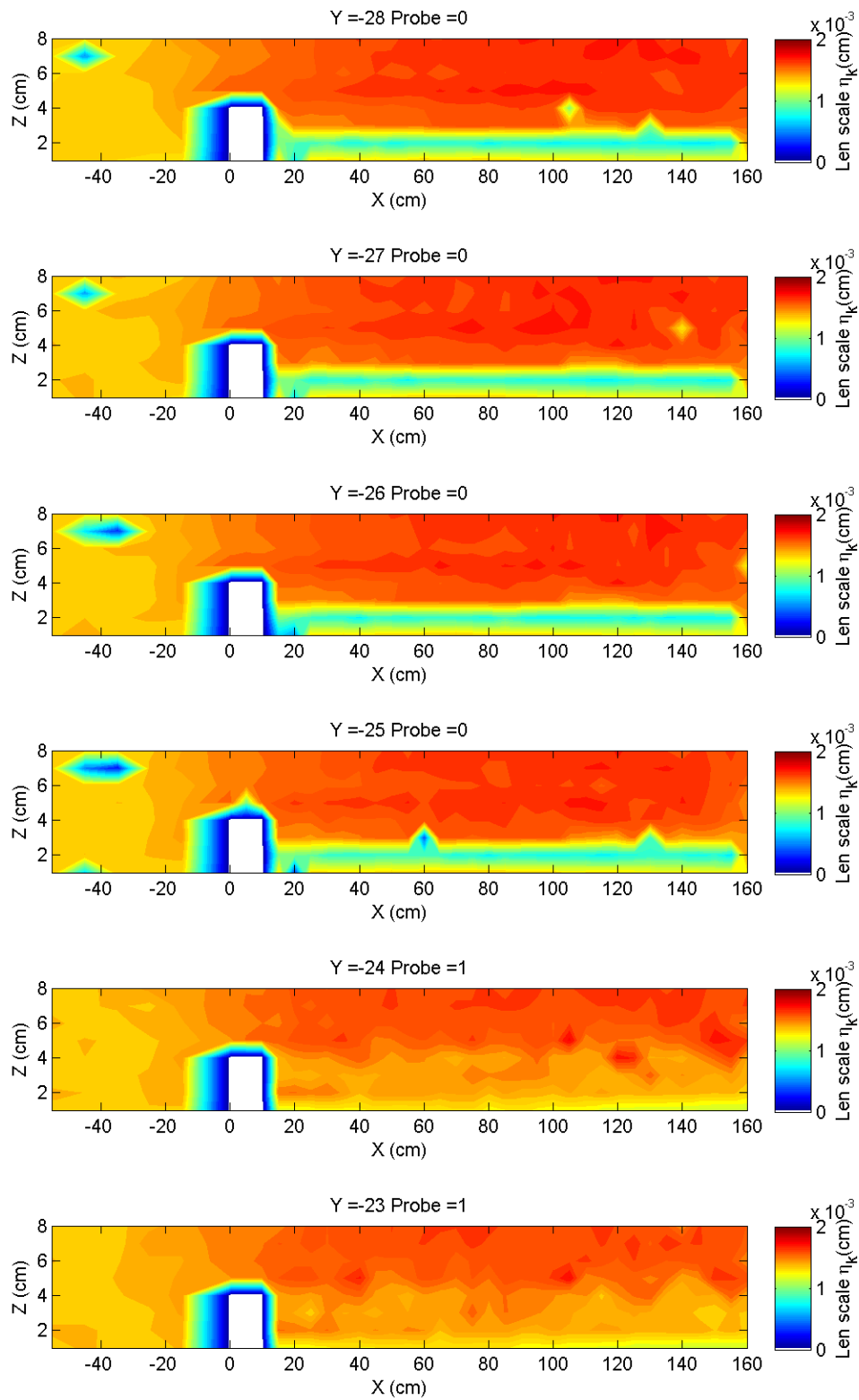


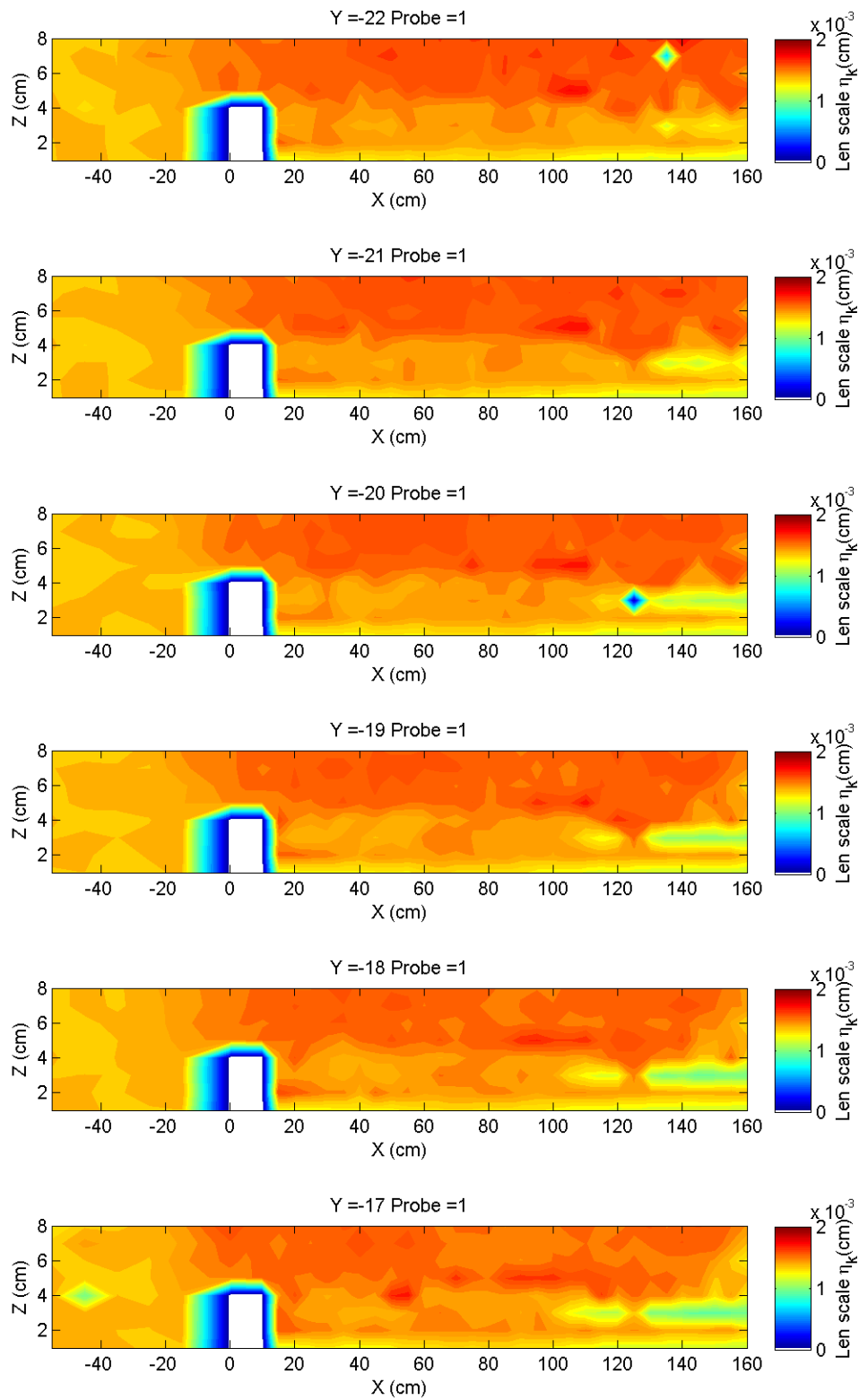


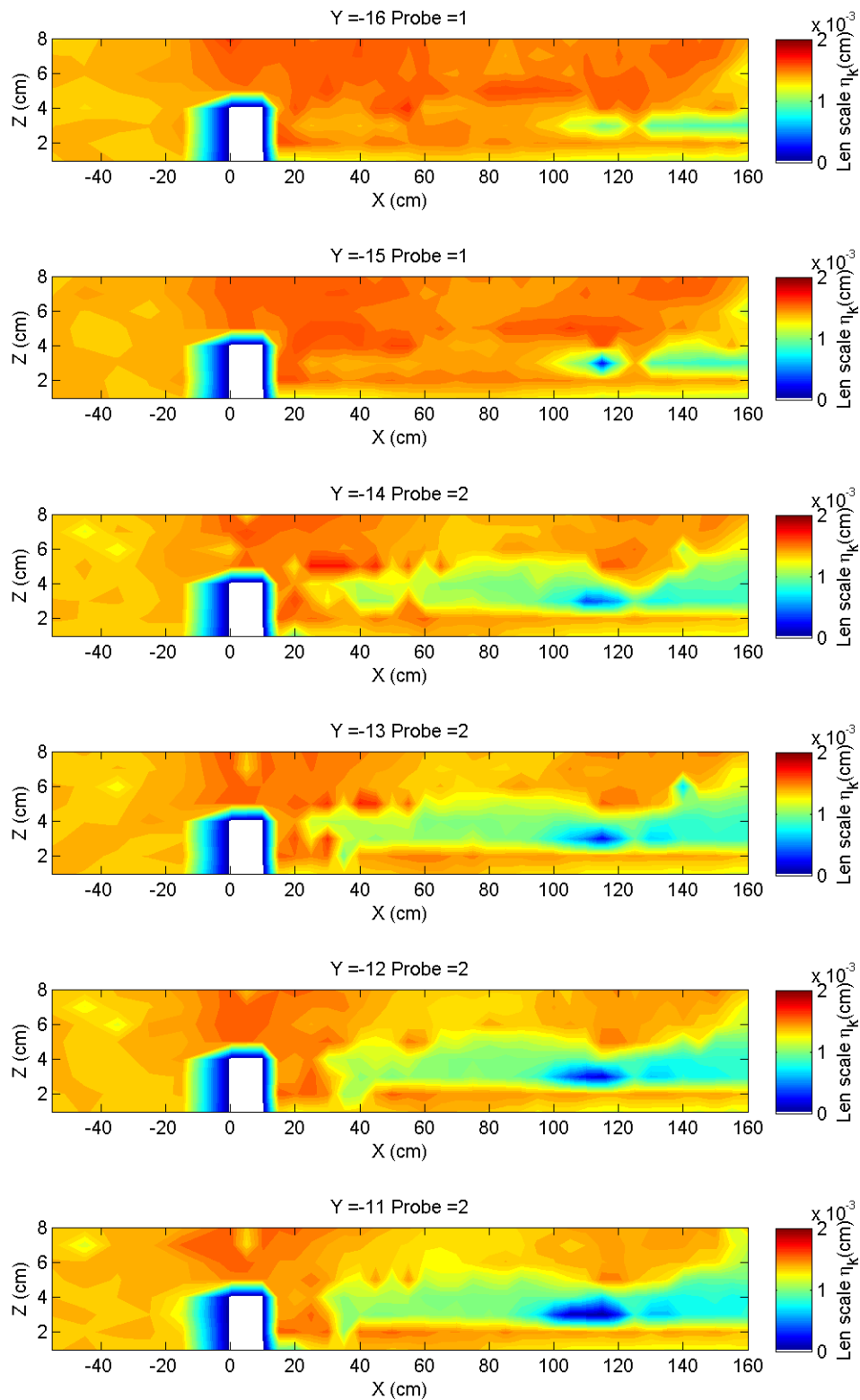


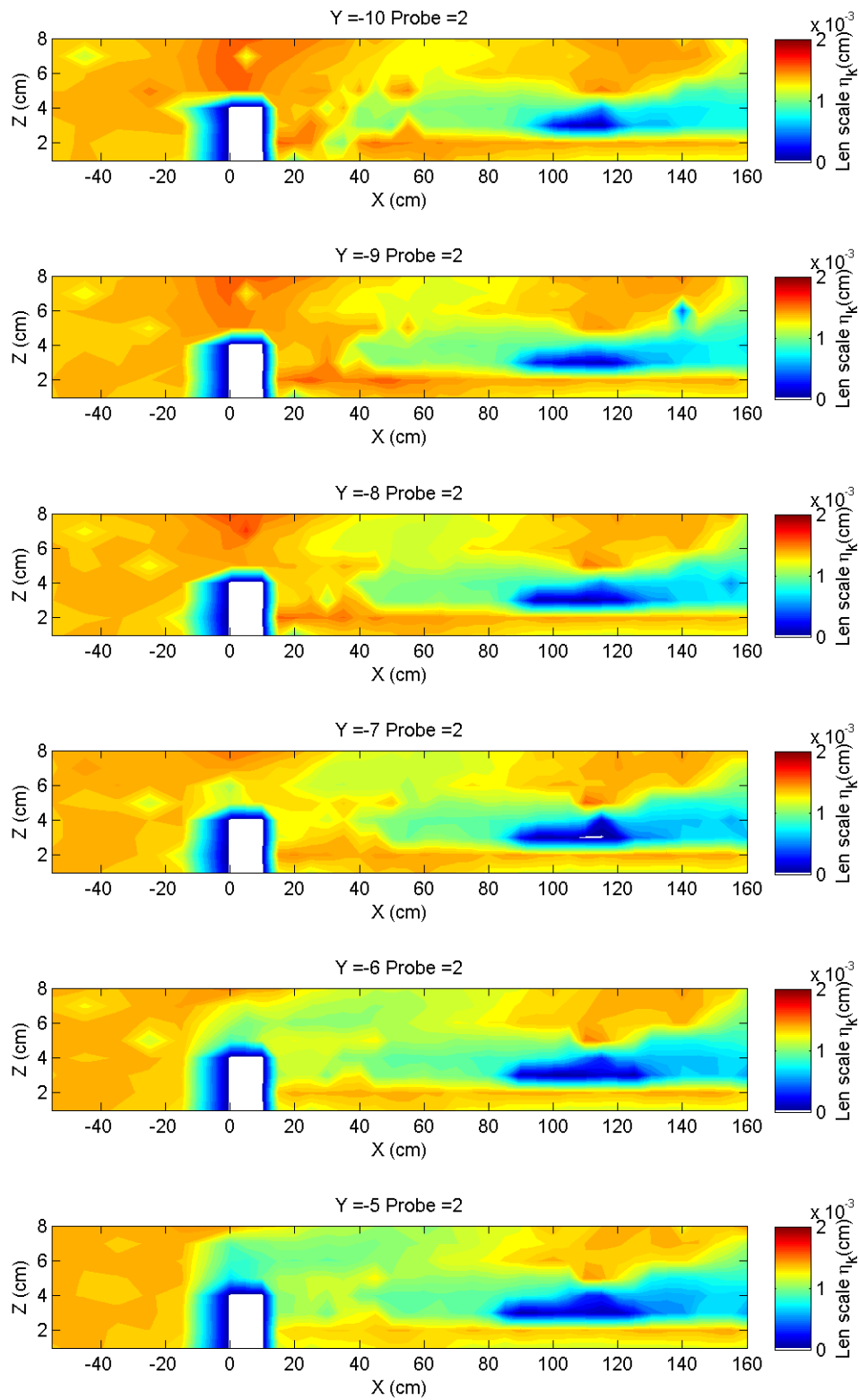
## Kolmogorov Length Scale $\eta_k$ in x and z-directions



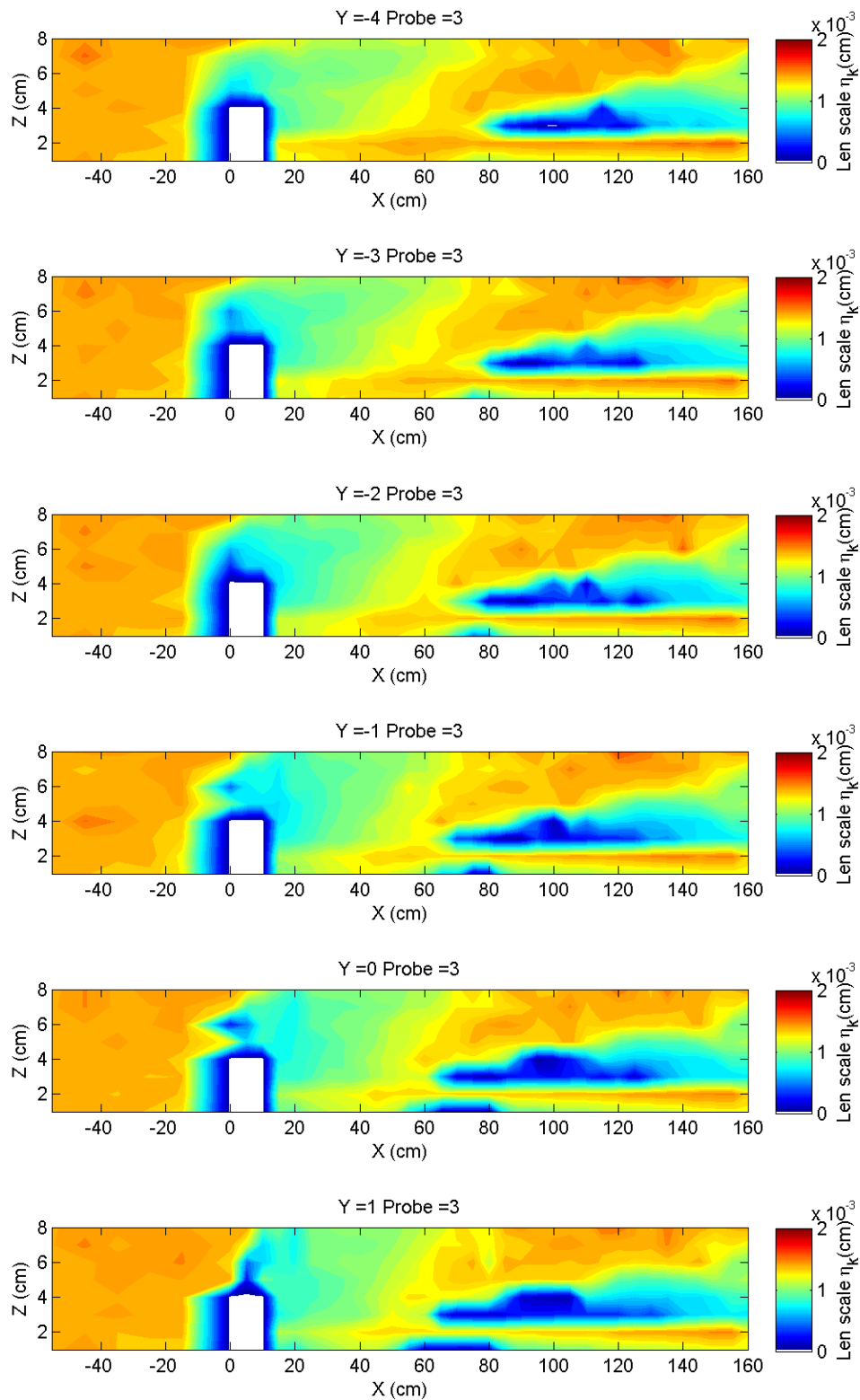


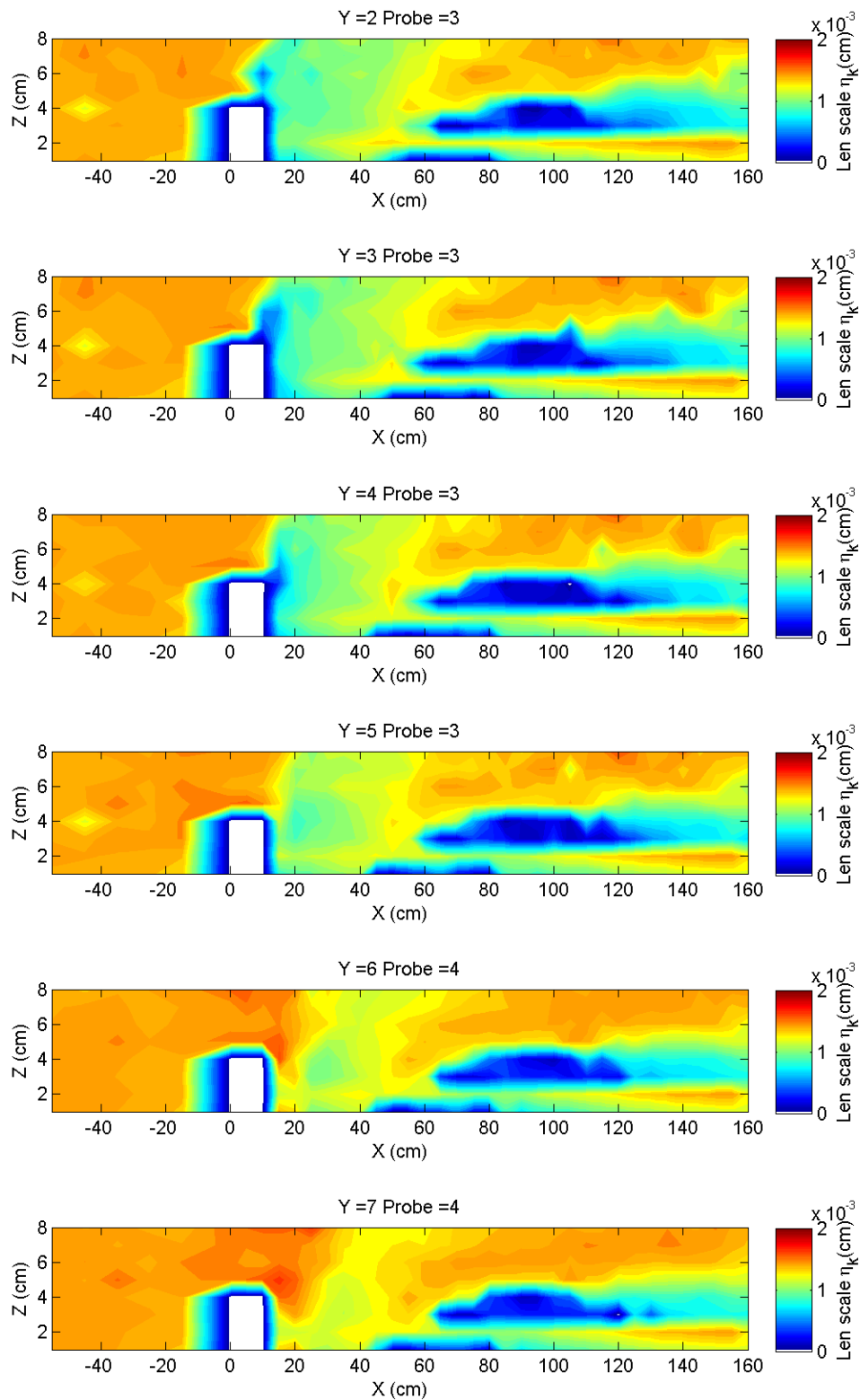


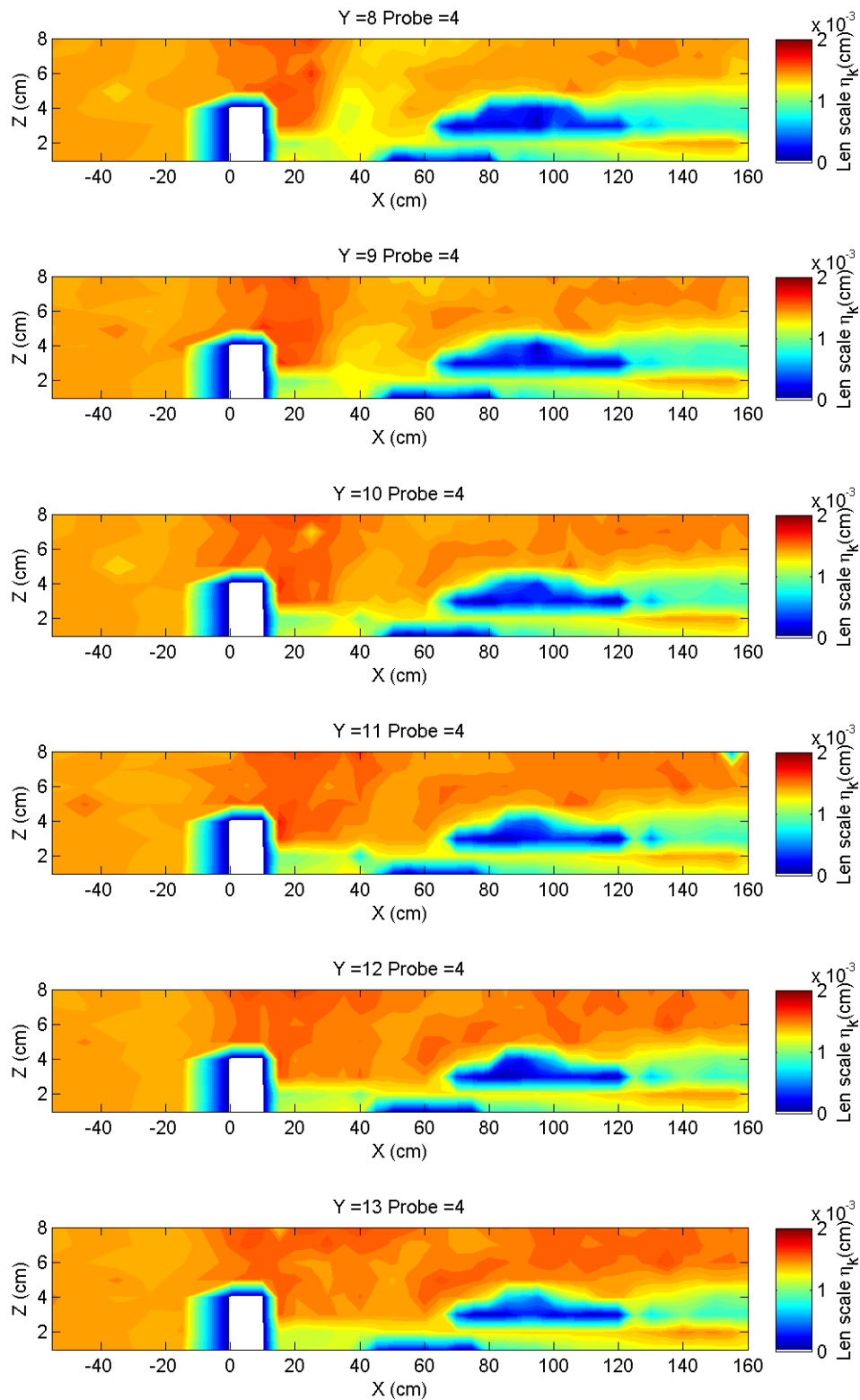


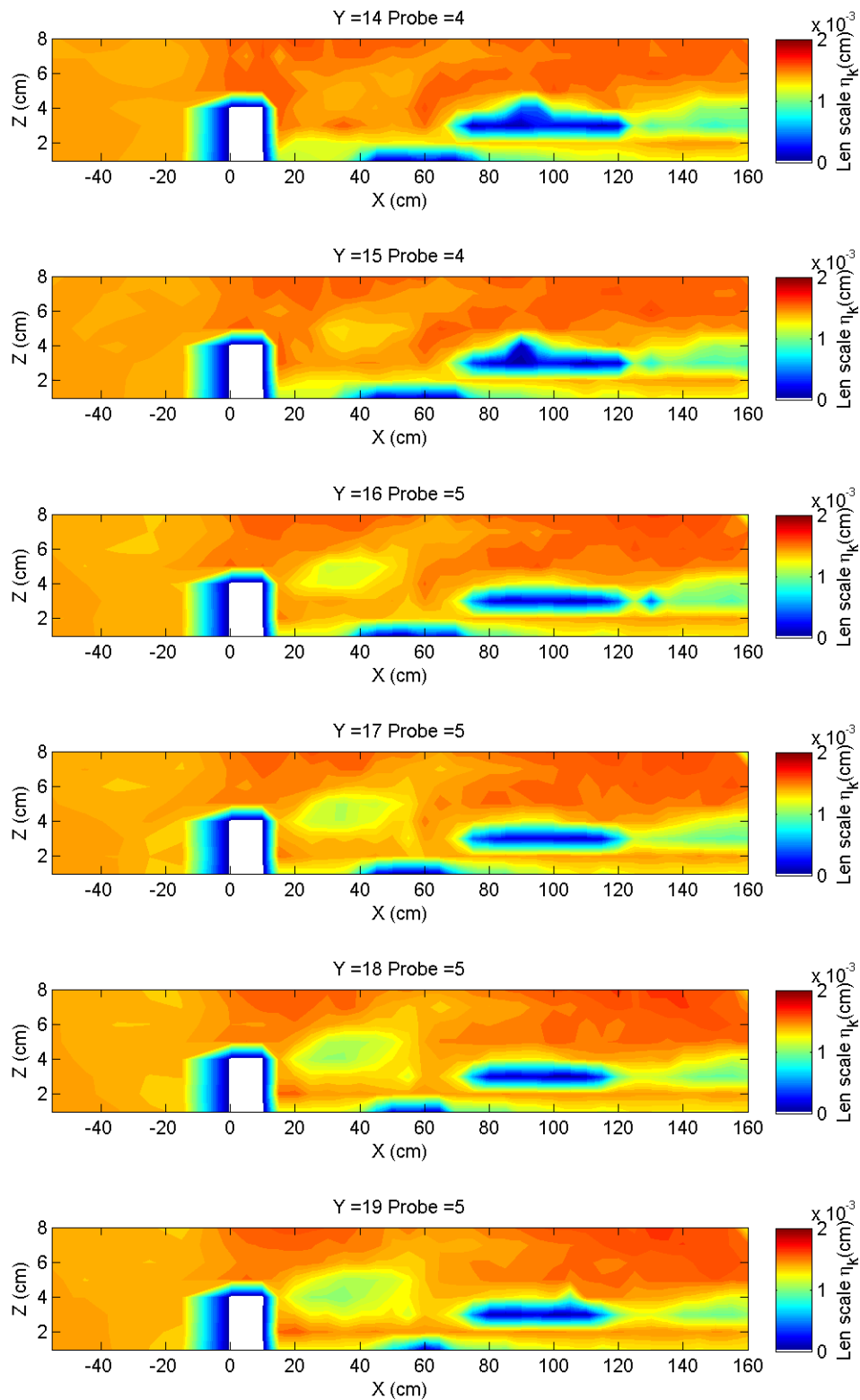


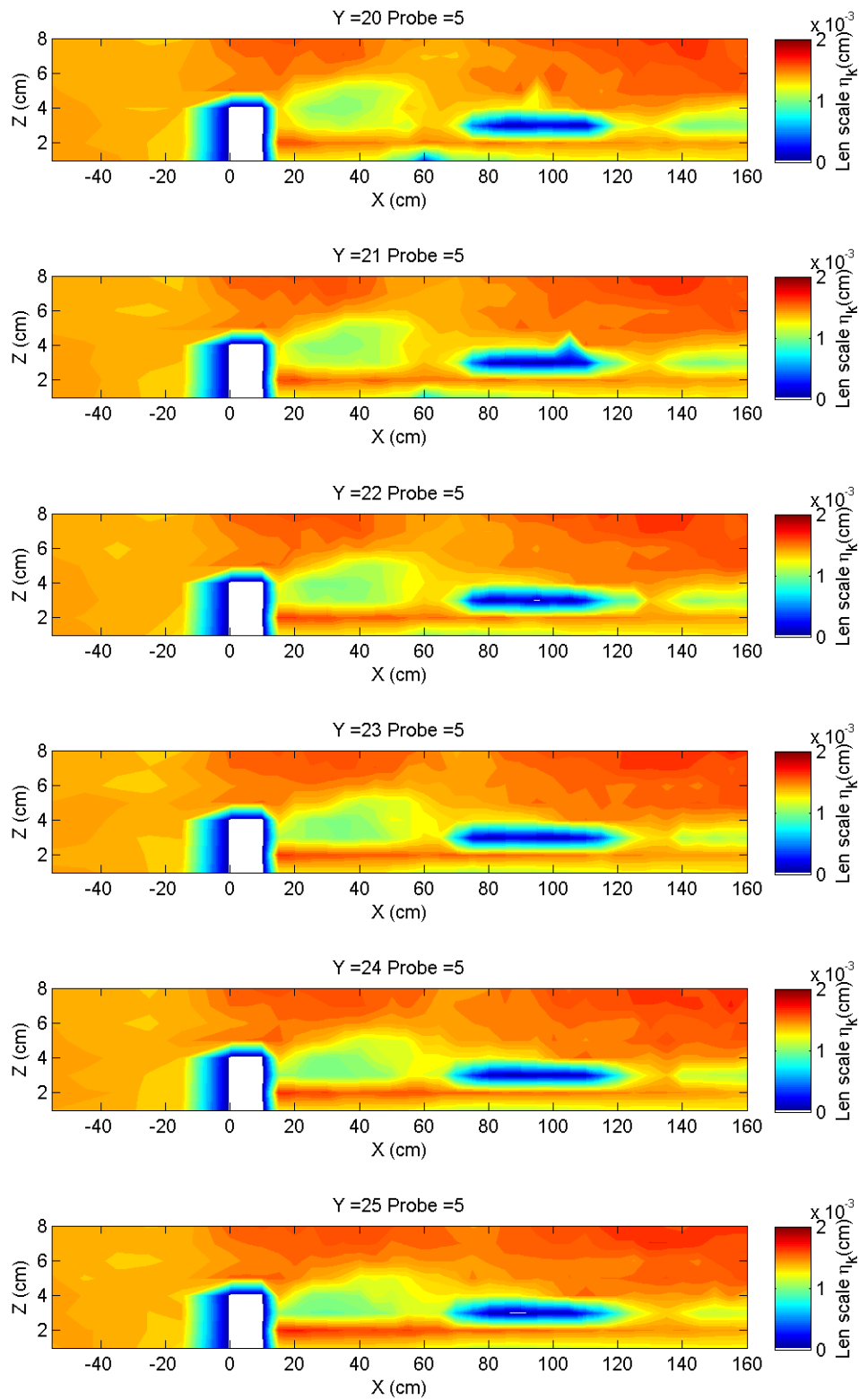


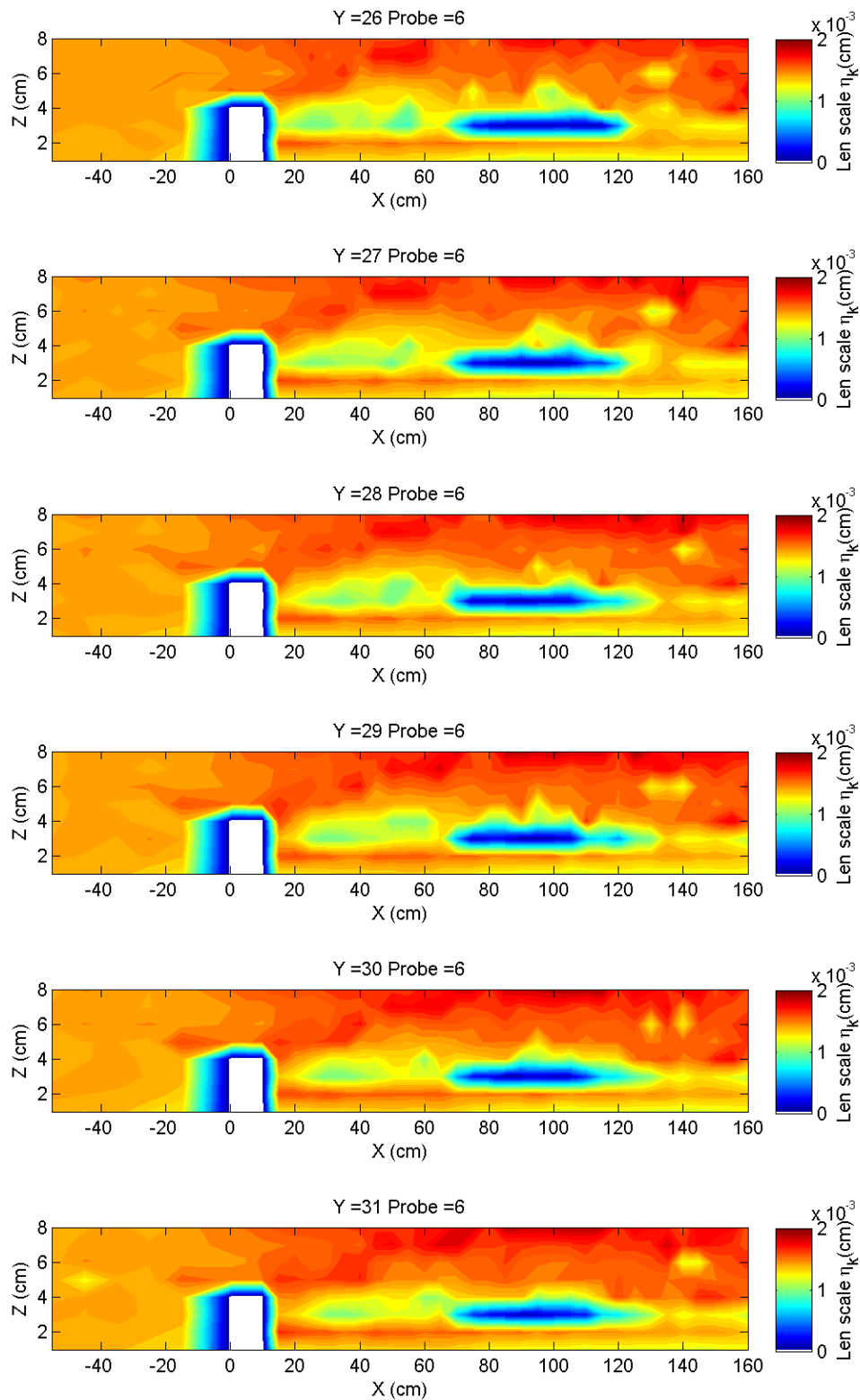


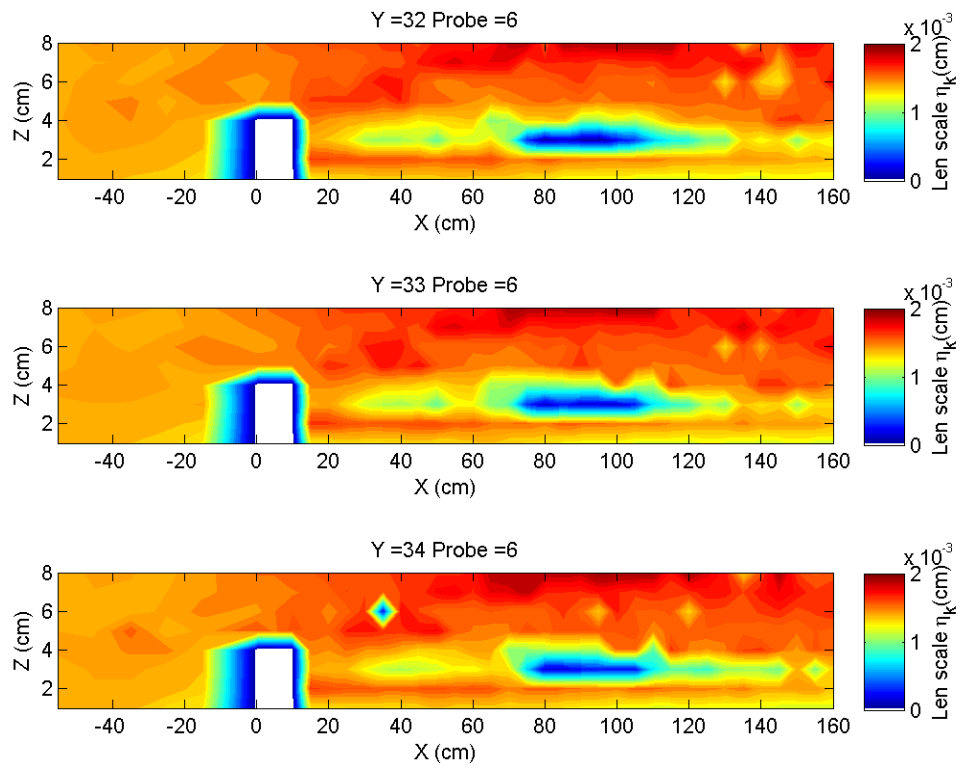






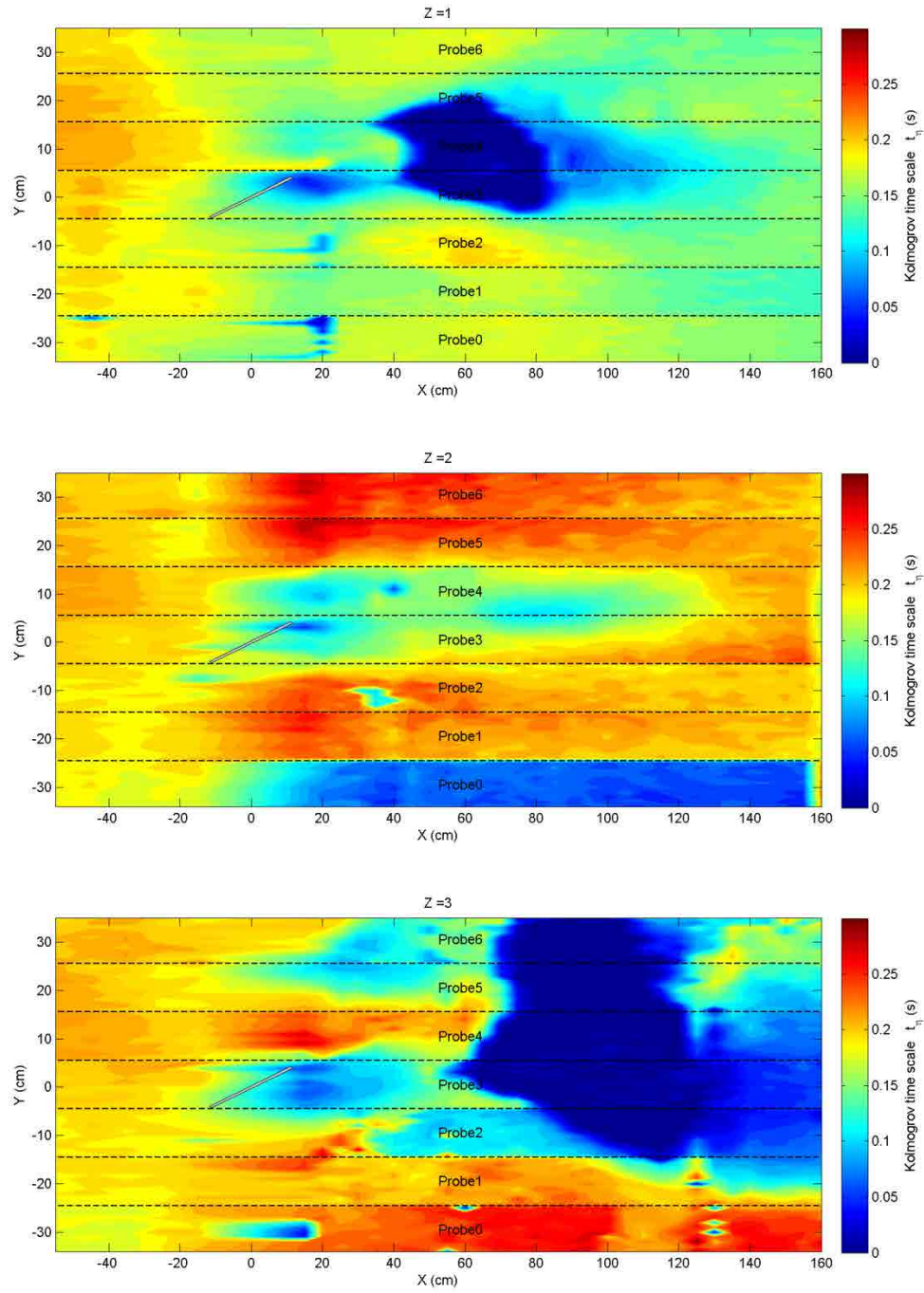




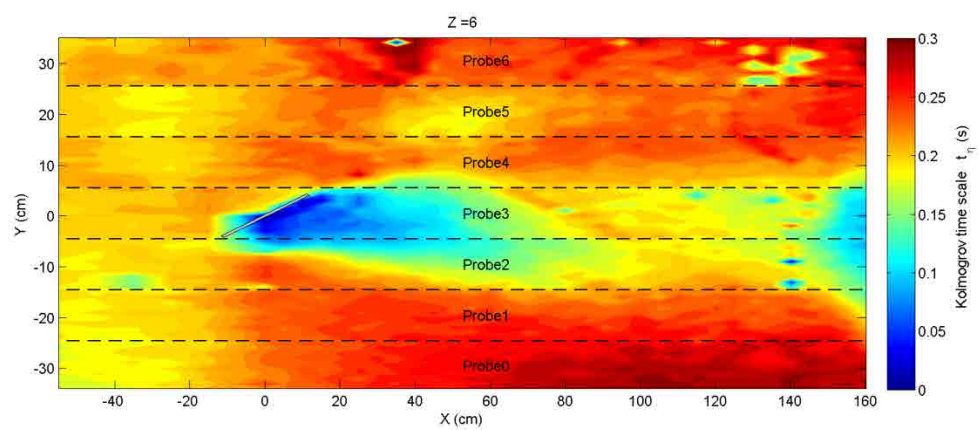
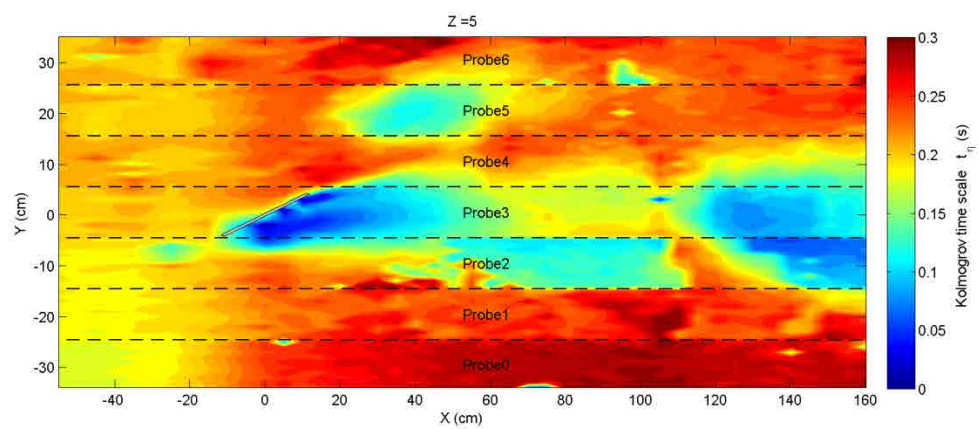
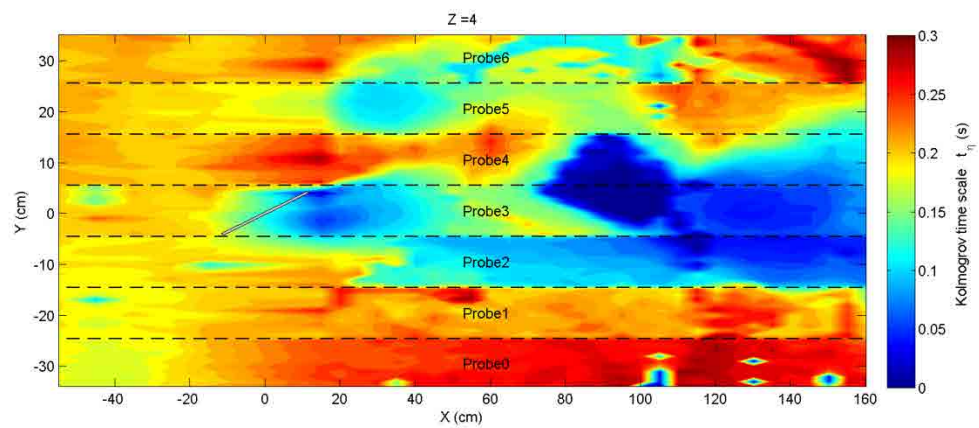


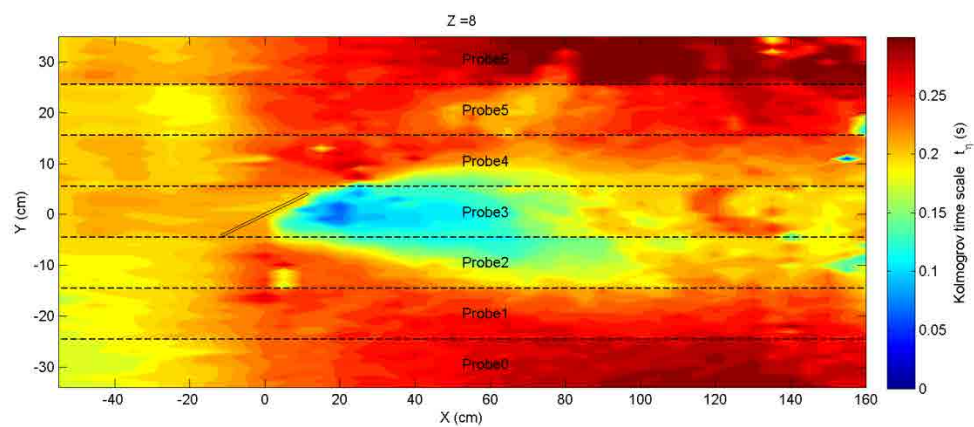
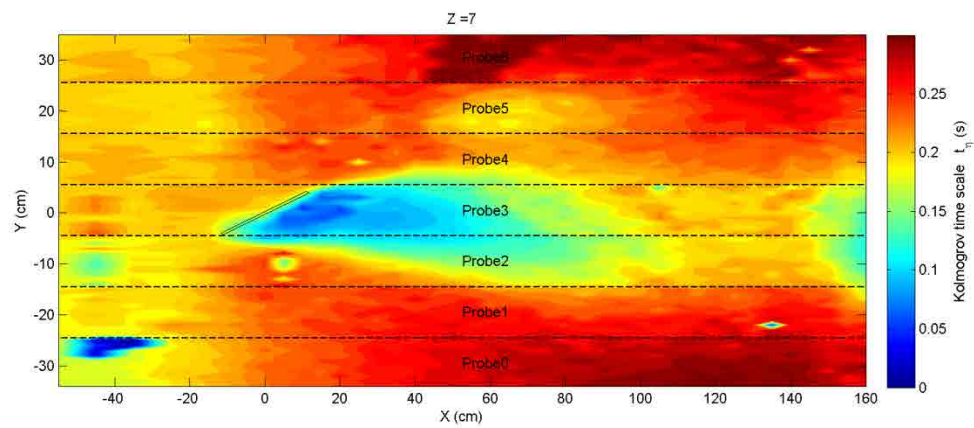
## 2. Kolmogorov Time Scale $t_\eta$

### Kolmogorov Time Scale $t_\eta$ in x and y-Directions

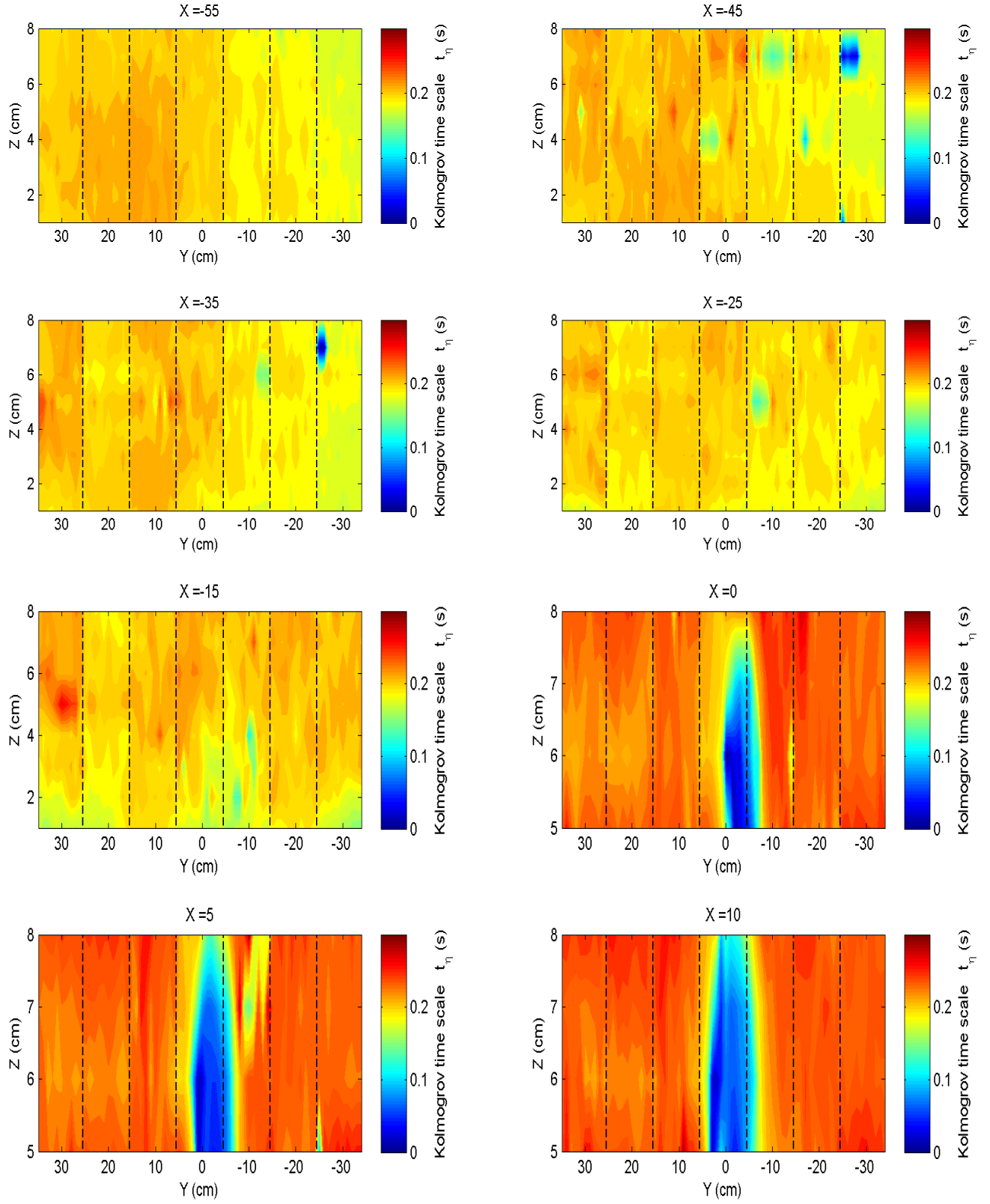


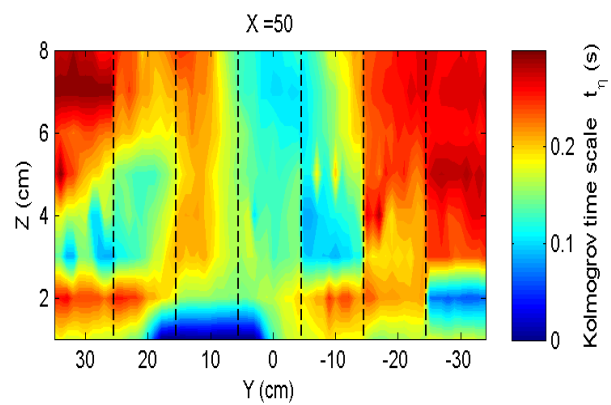
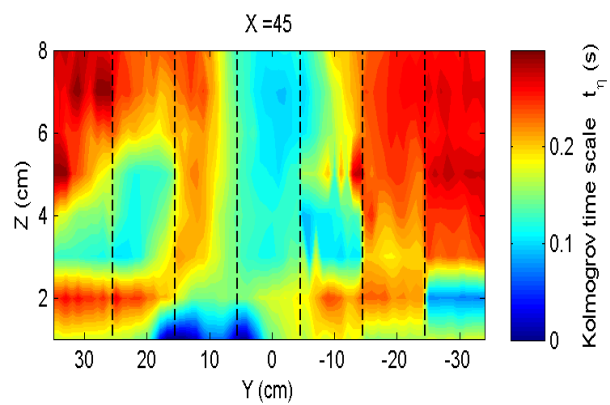
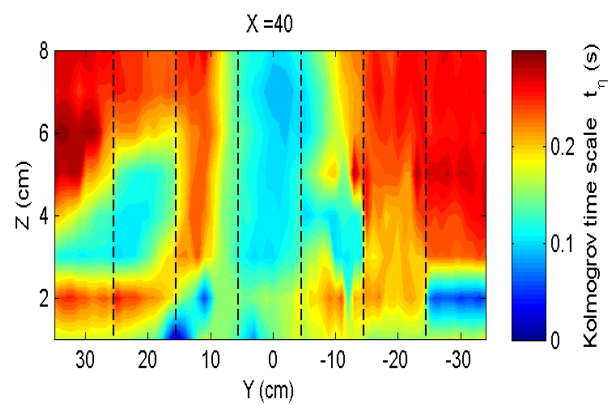
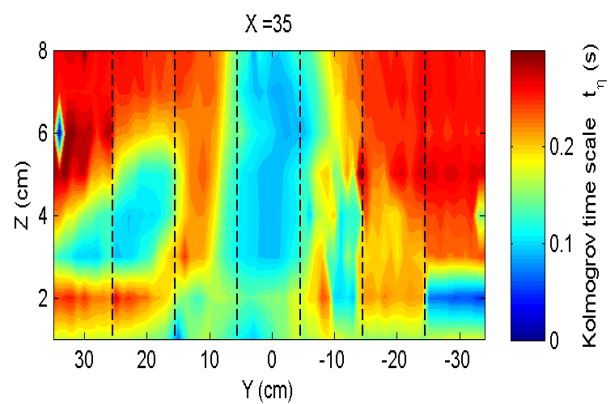
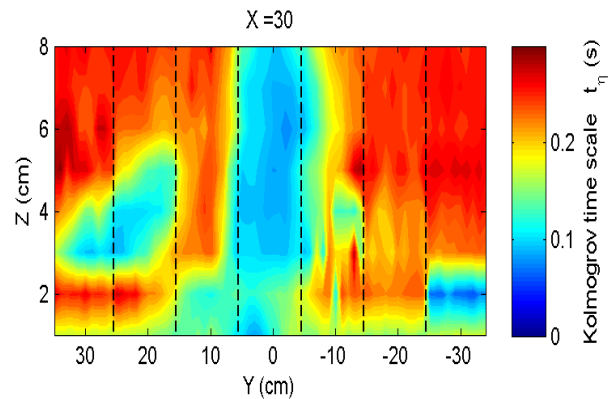
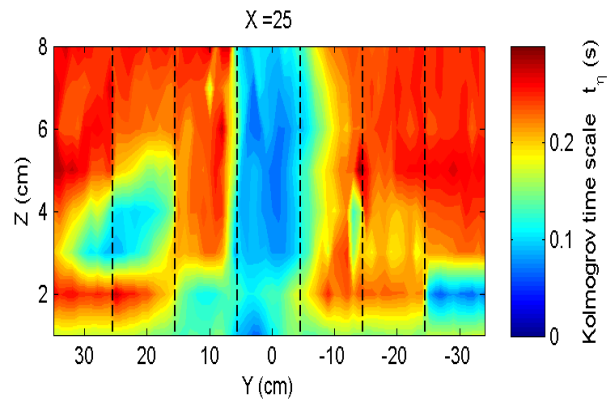
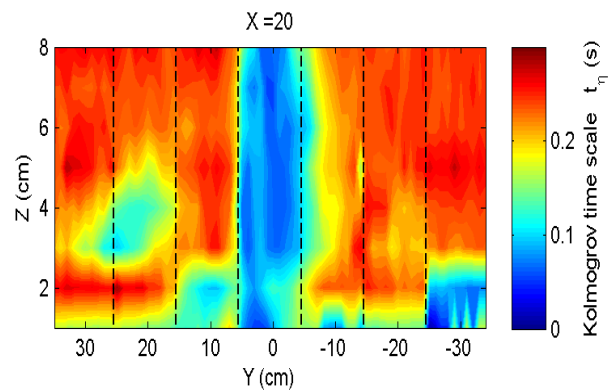
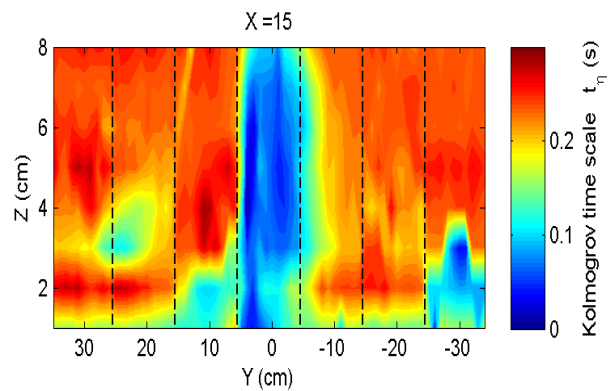


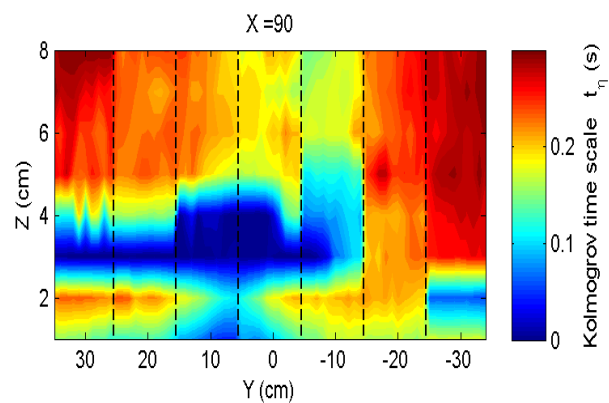
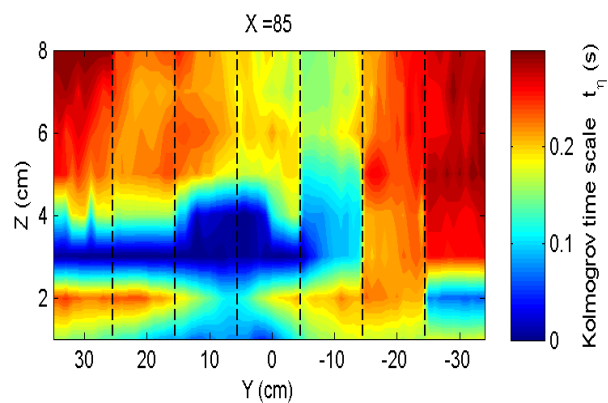
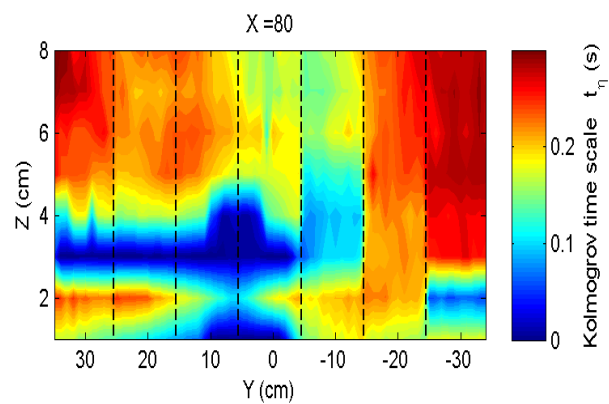
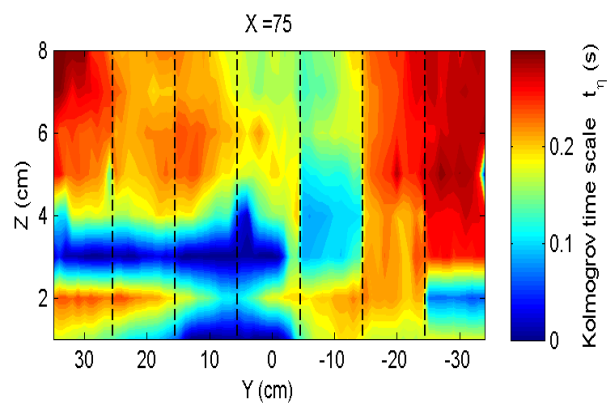
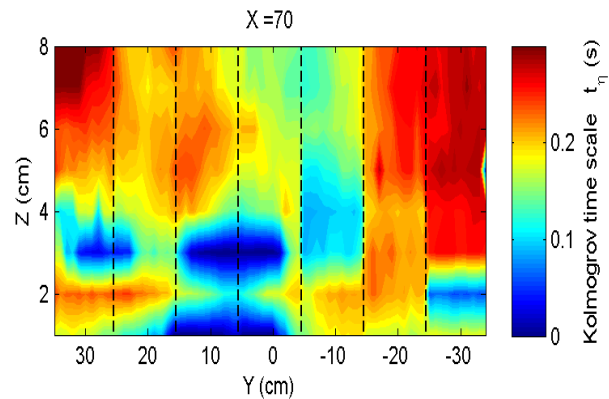
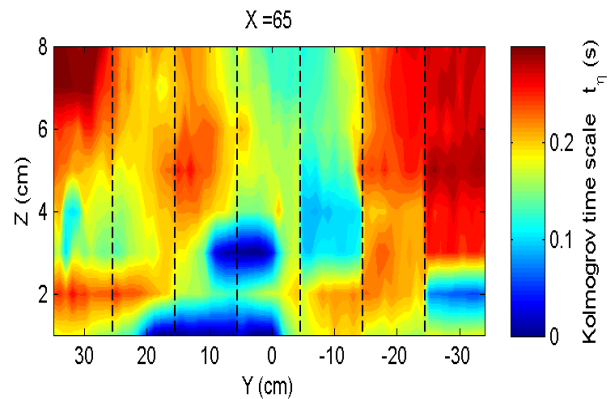
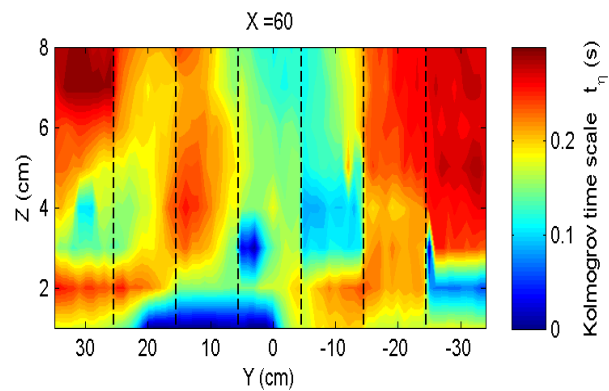
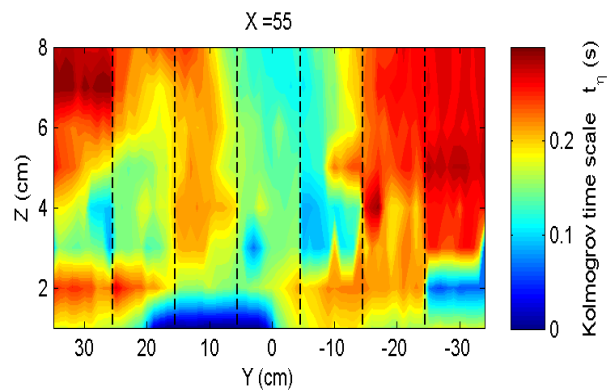




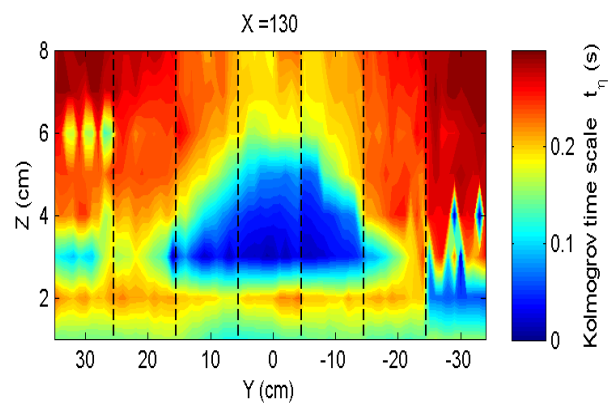
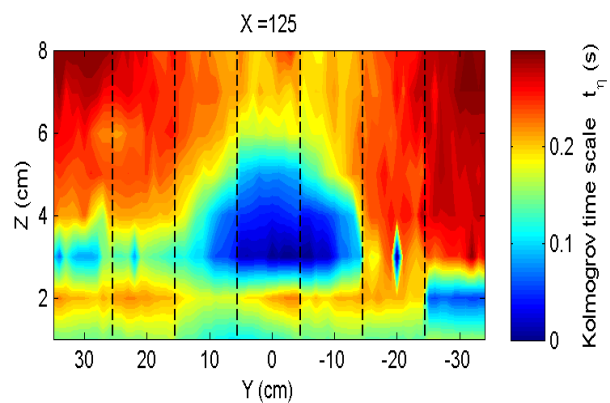
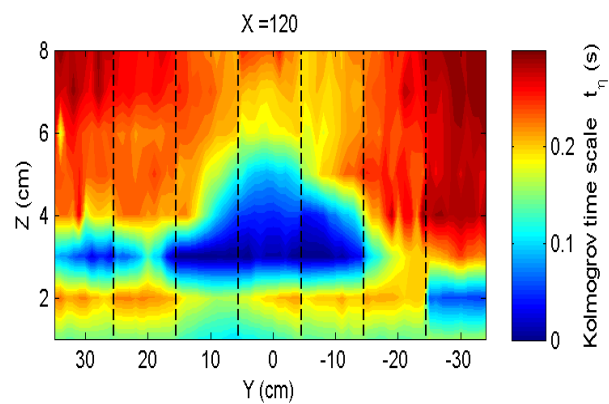
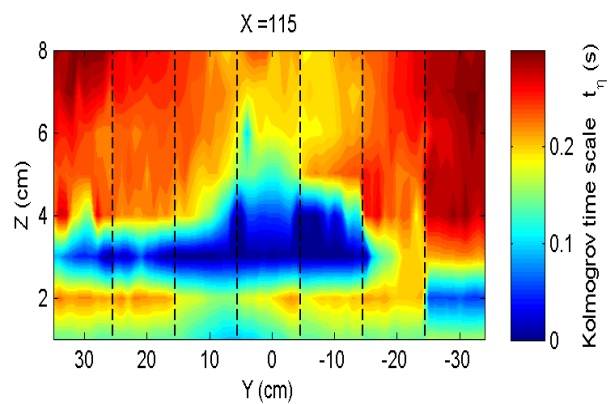
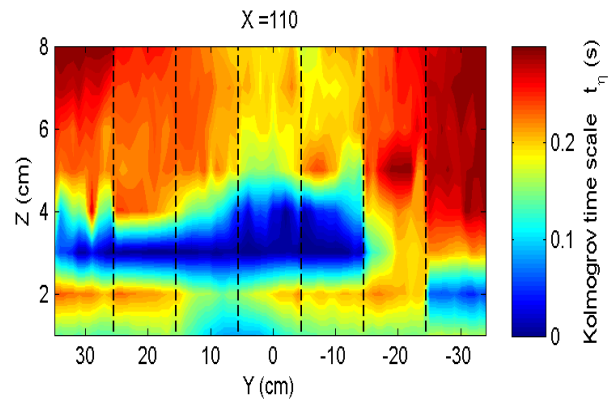
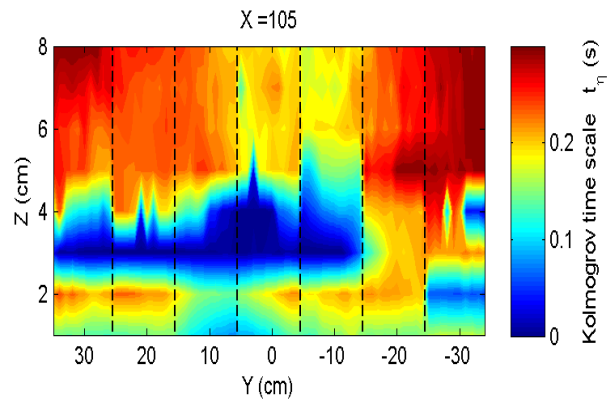
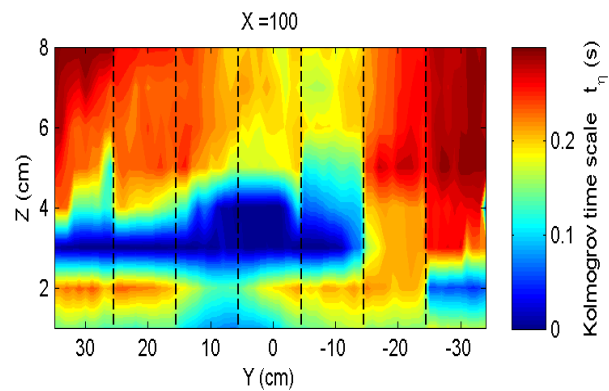
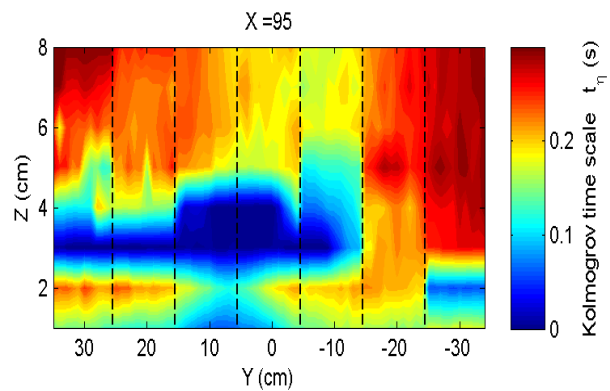
## Kolmogorov Time Scale $t_\eta$ in y and z-Directions

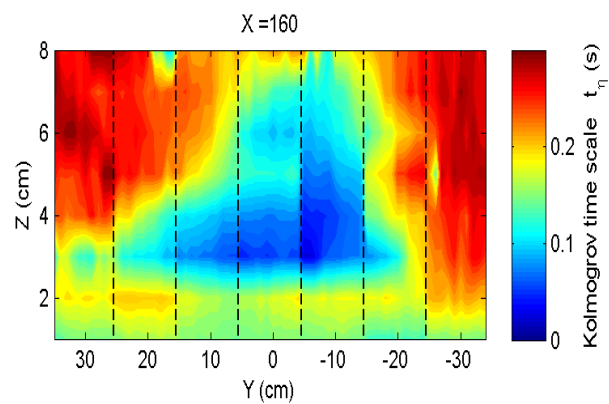
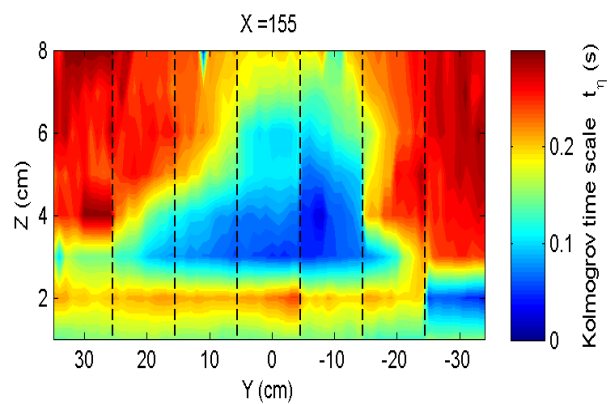
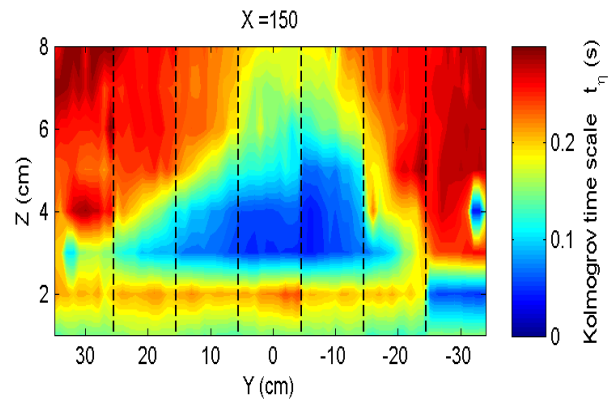
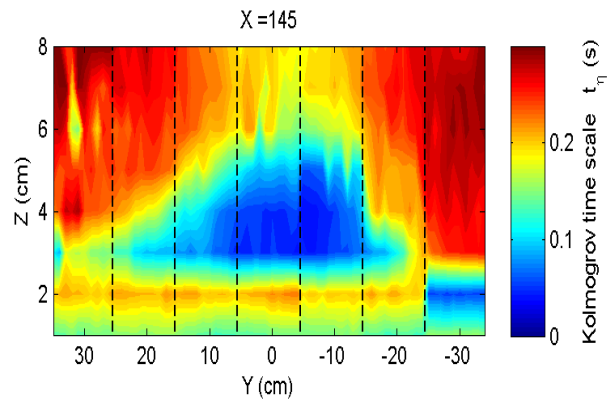
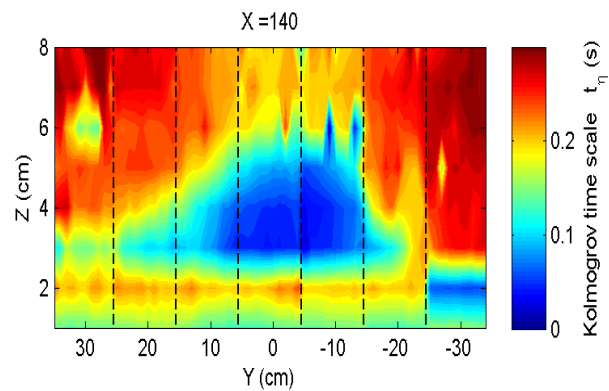
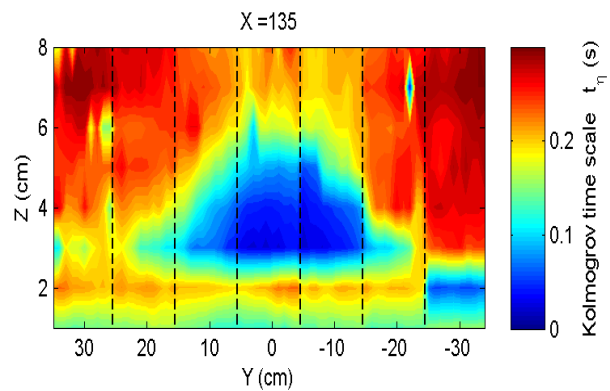




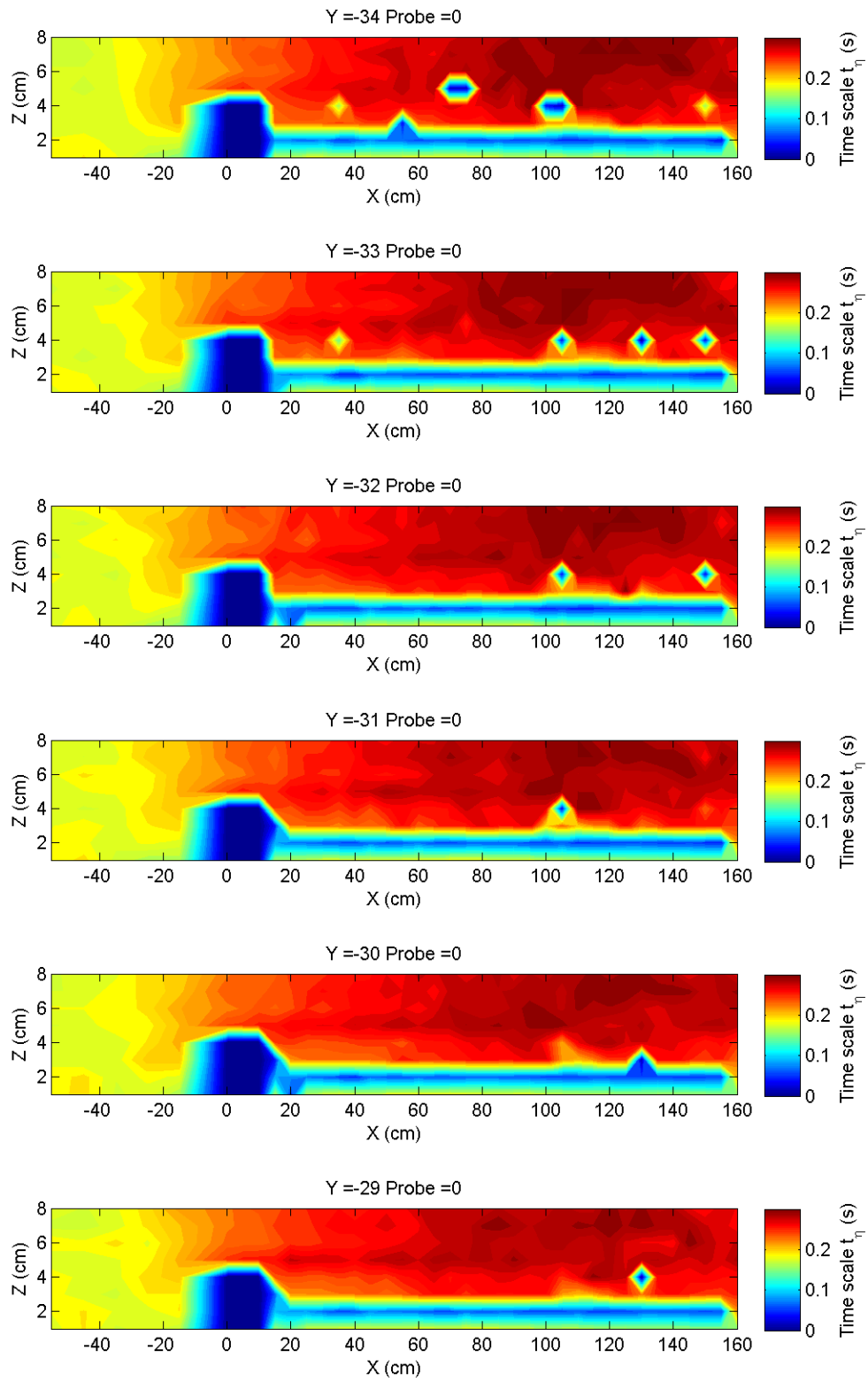




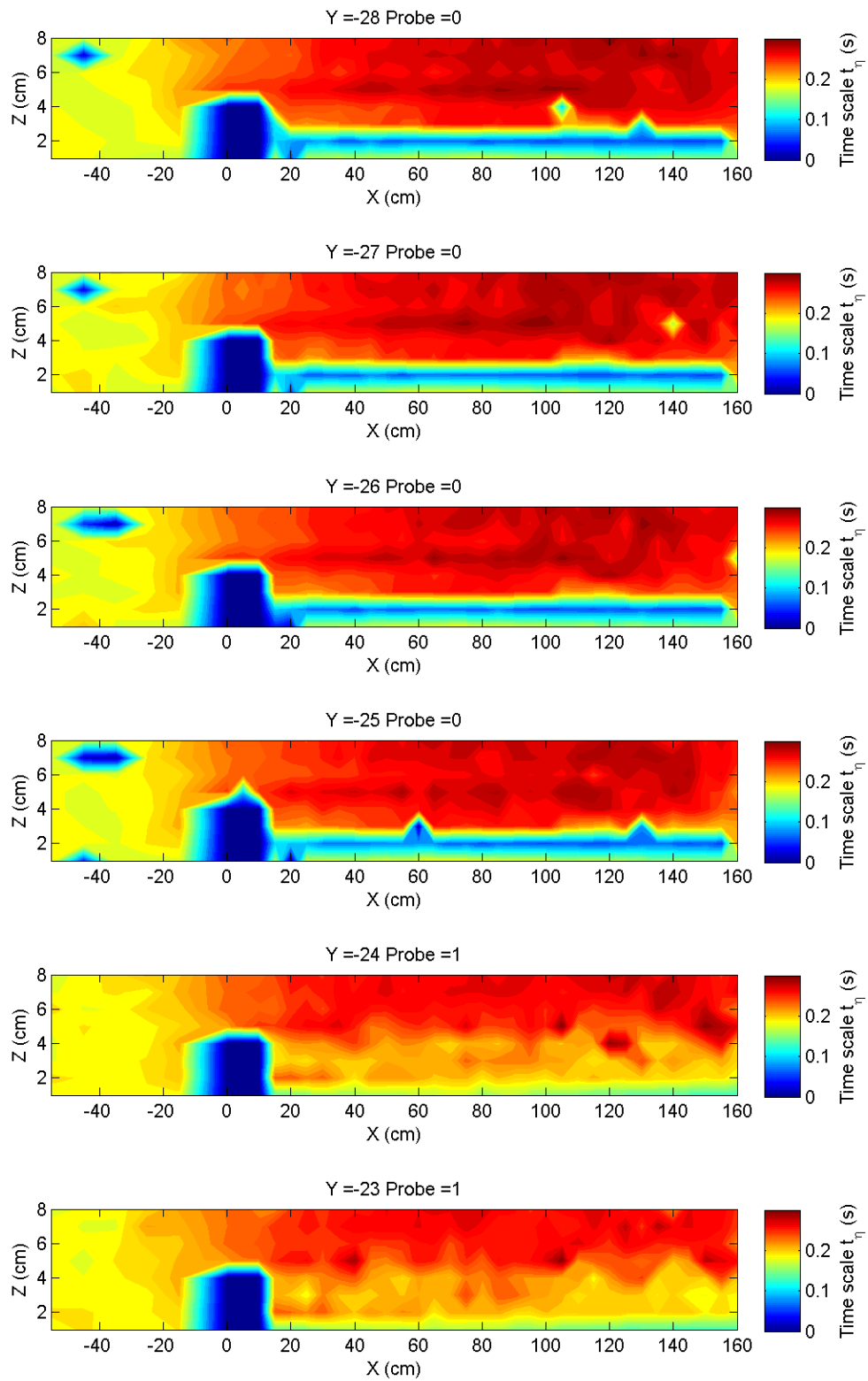


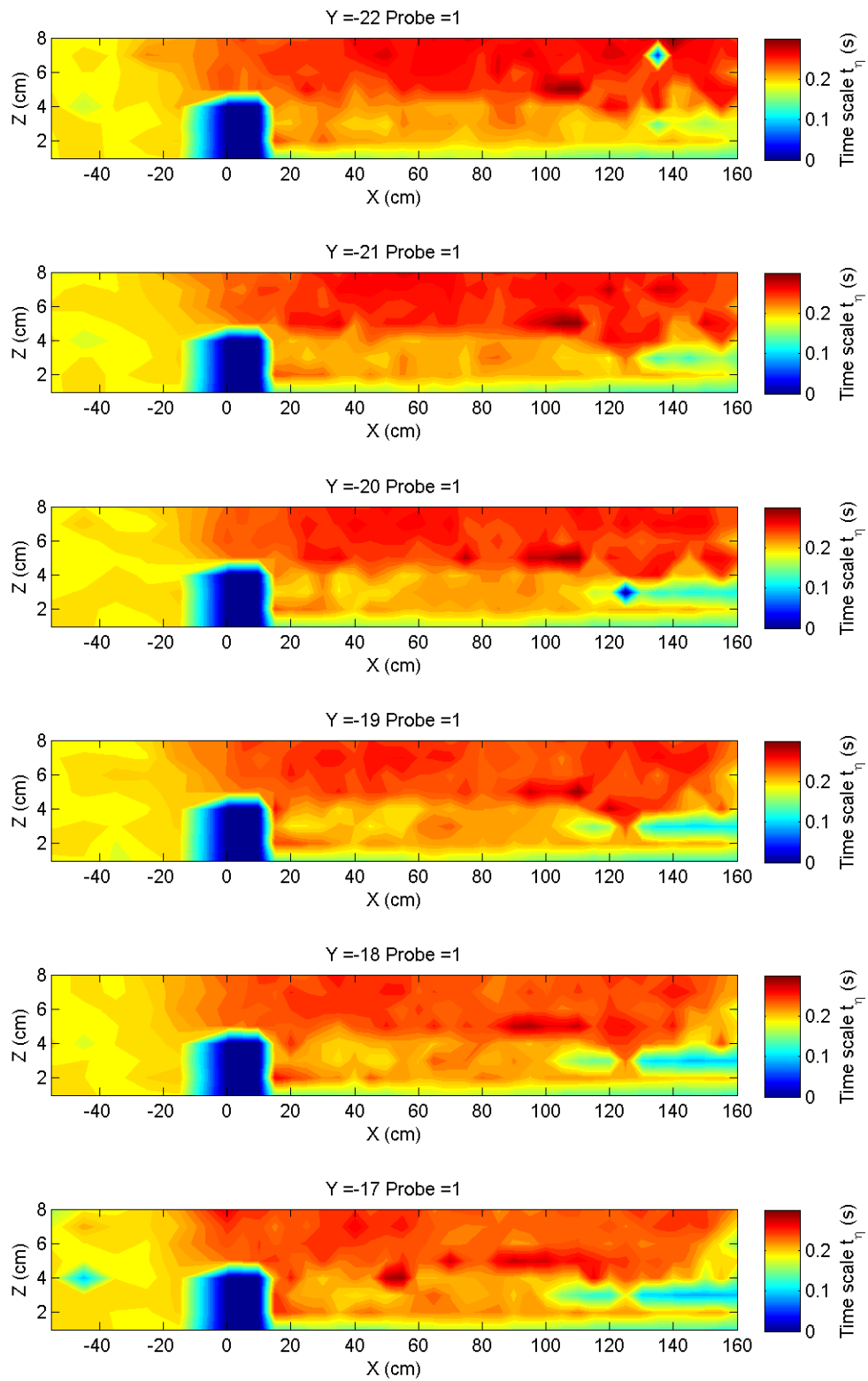


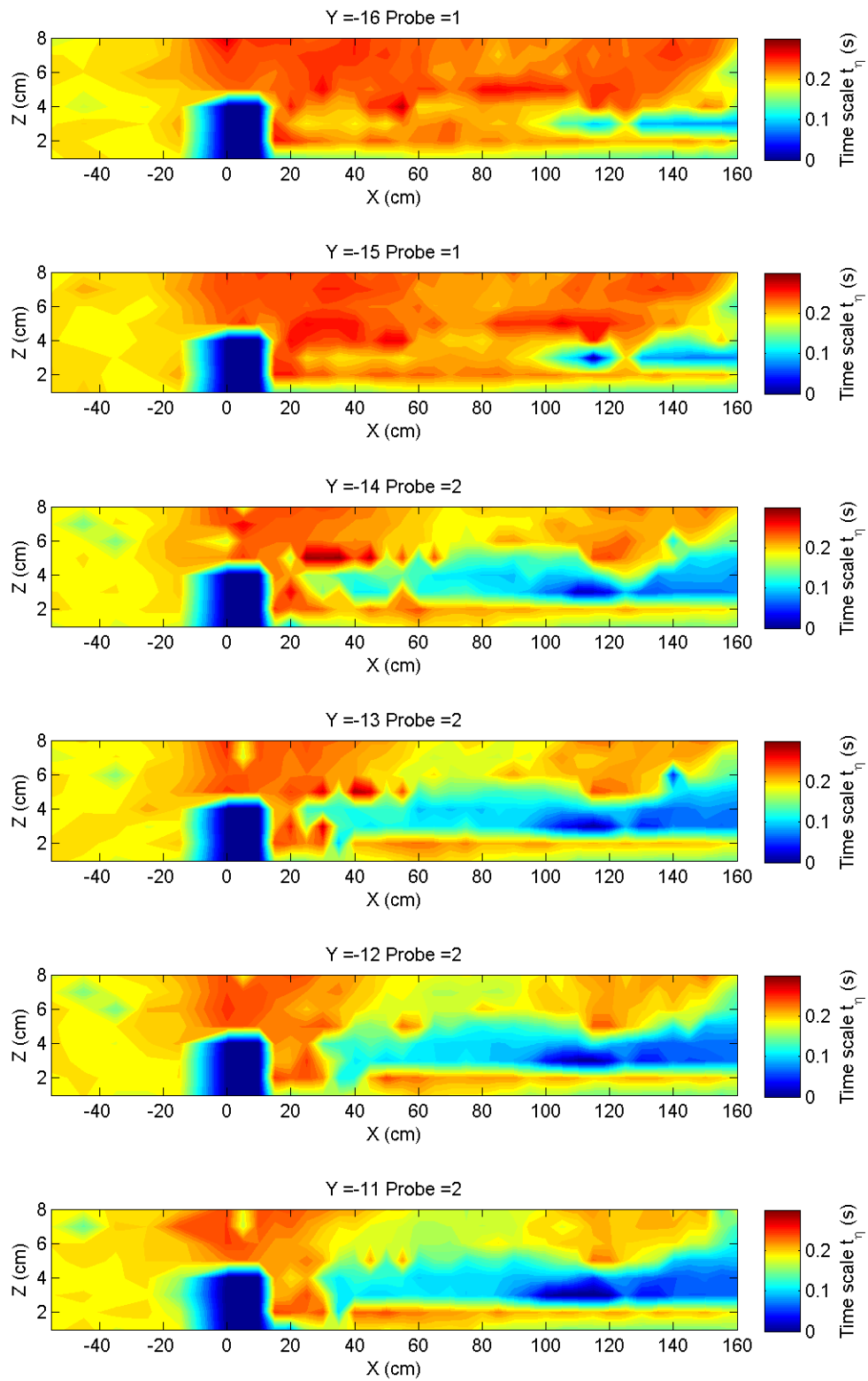
## Kolmogorov Time Scale $t_\eta$ in x and z-Directions

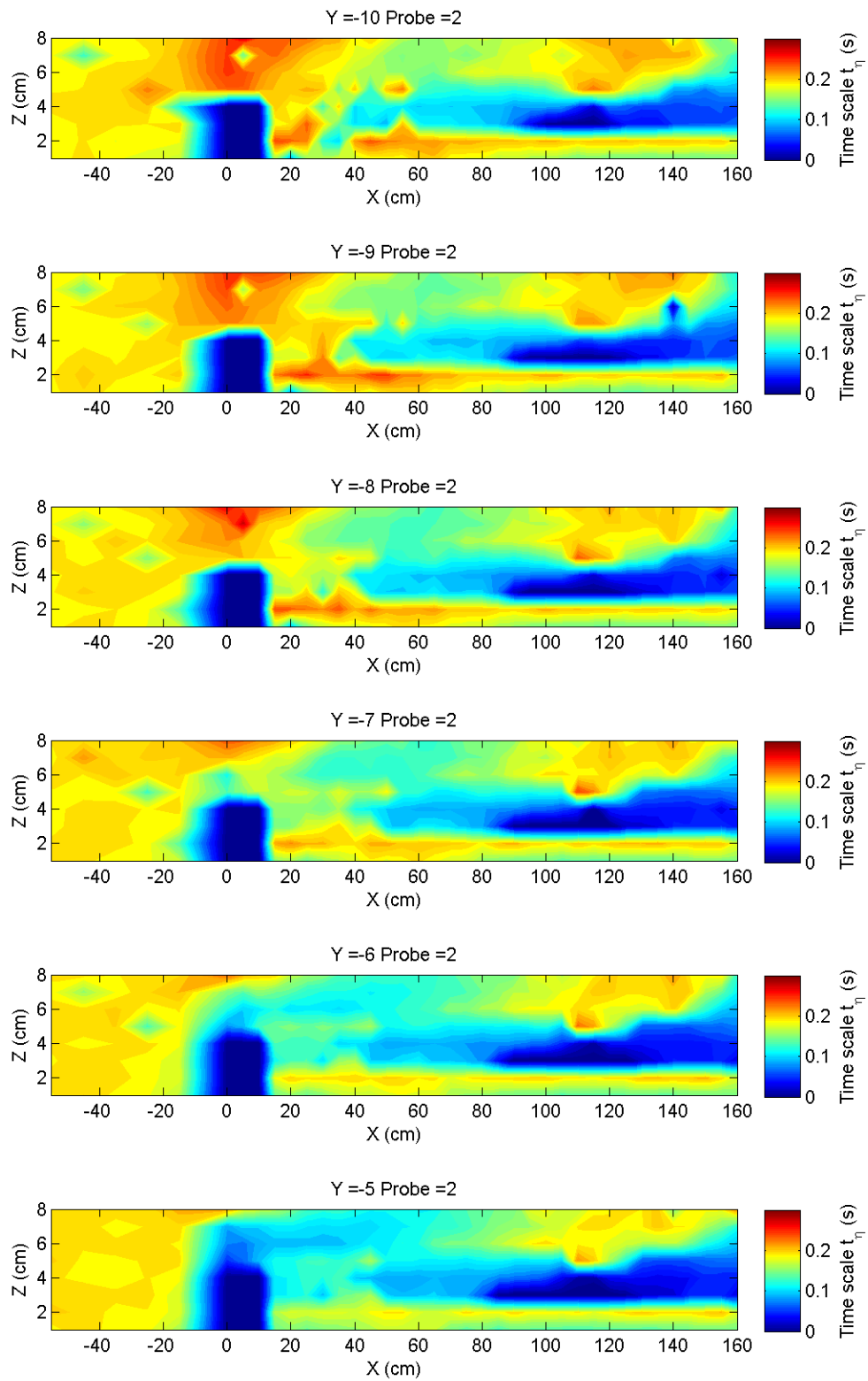


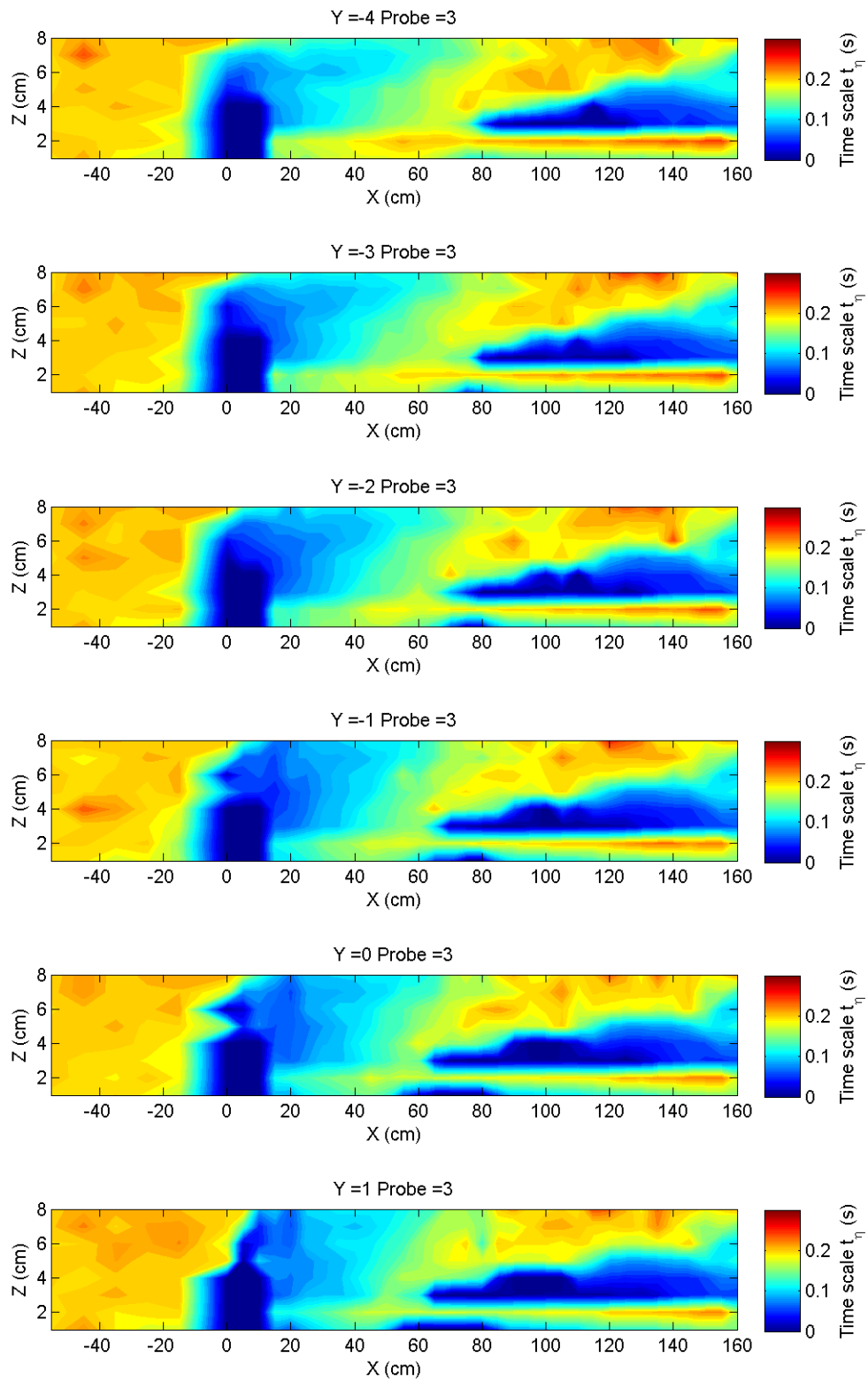


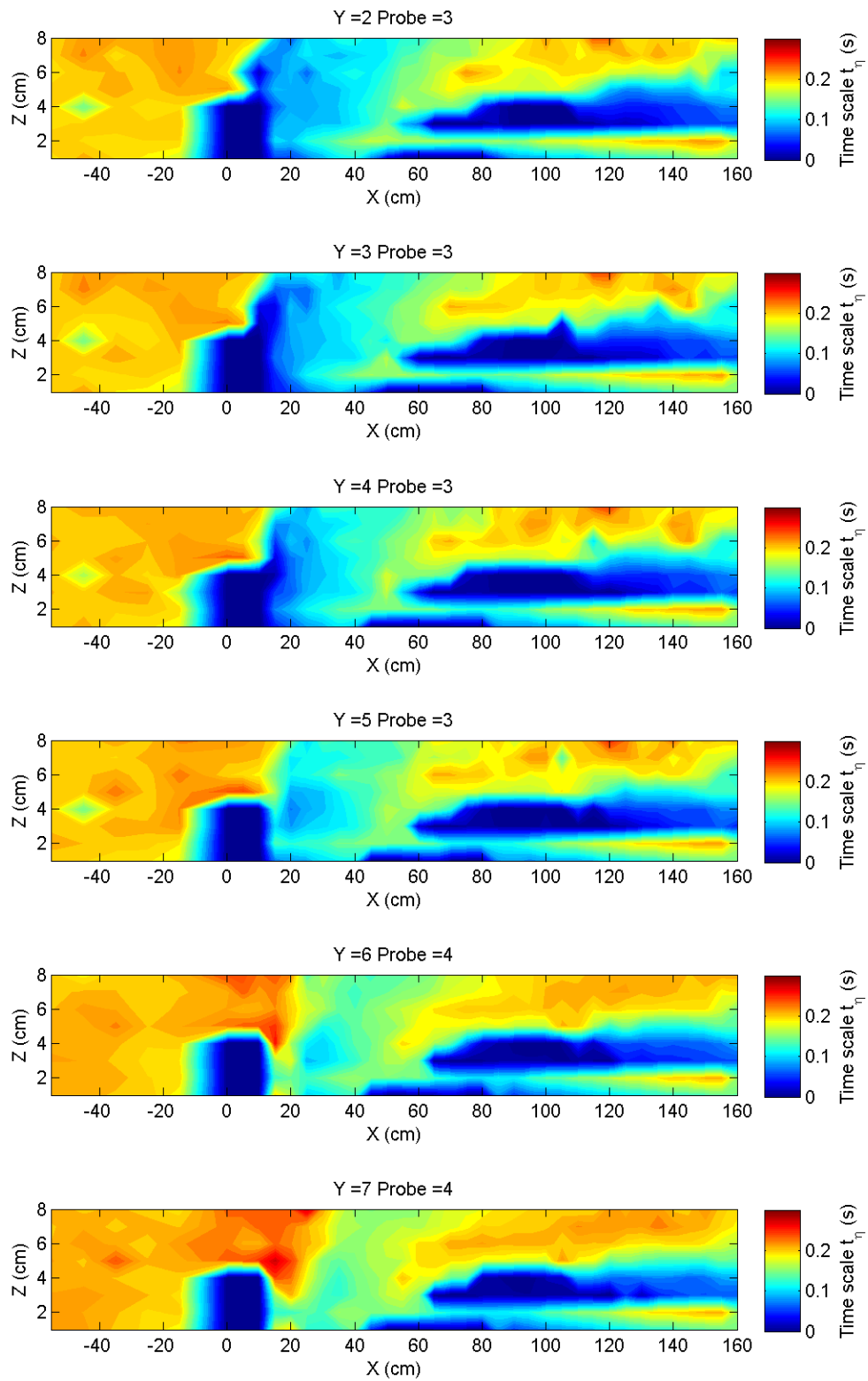


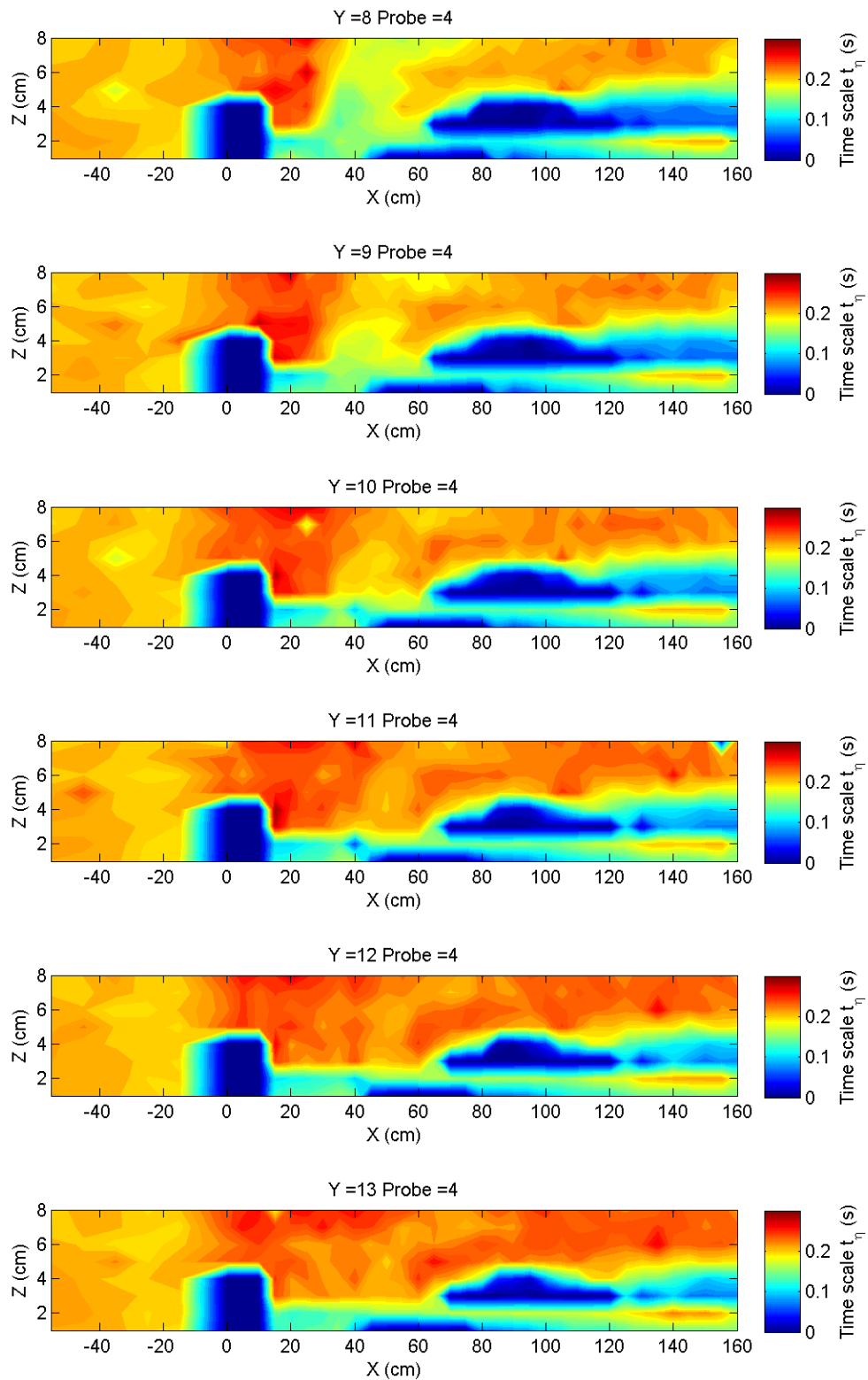


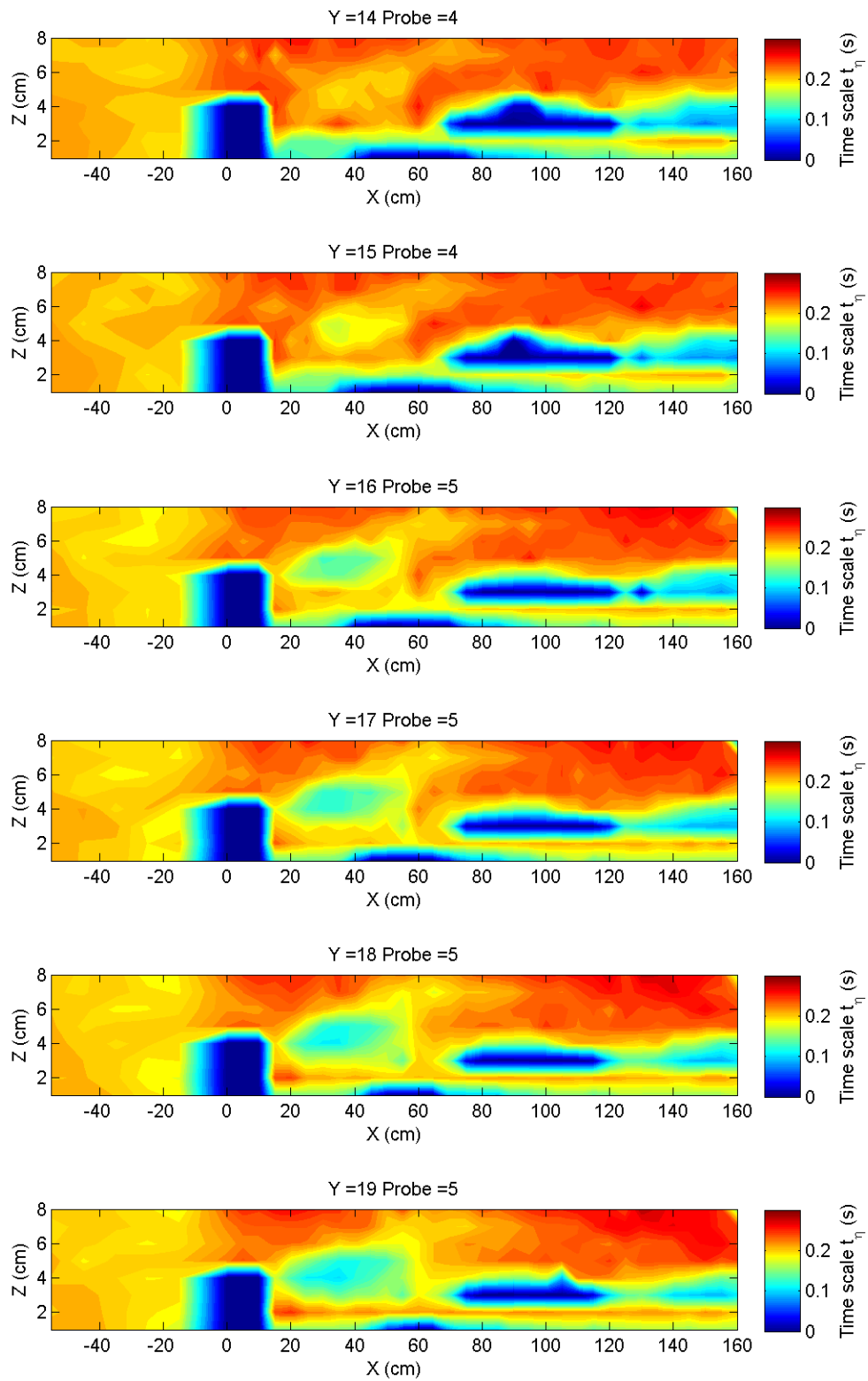




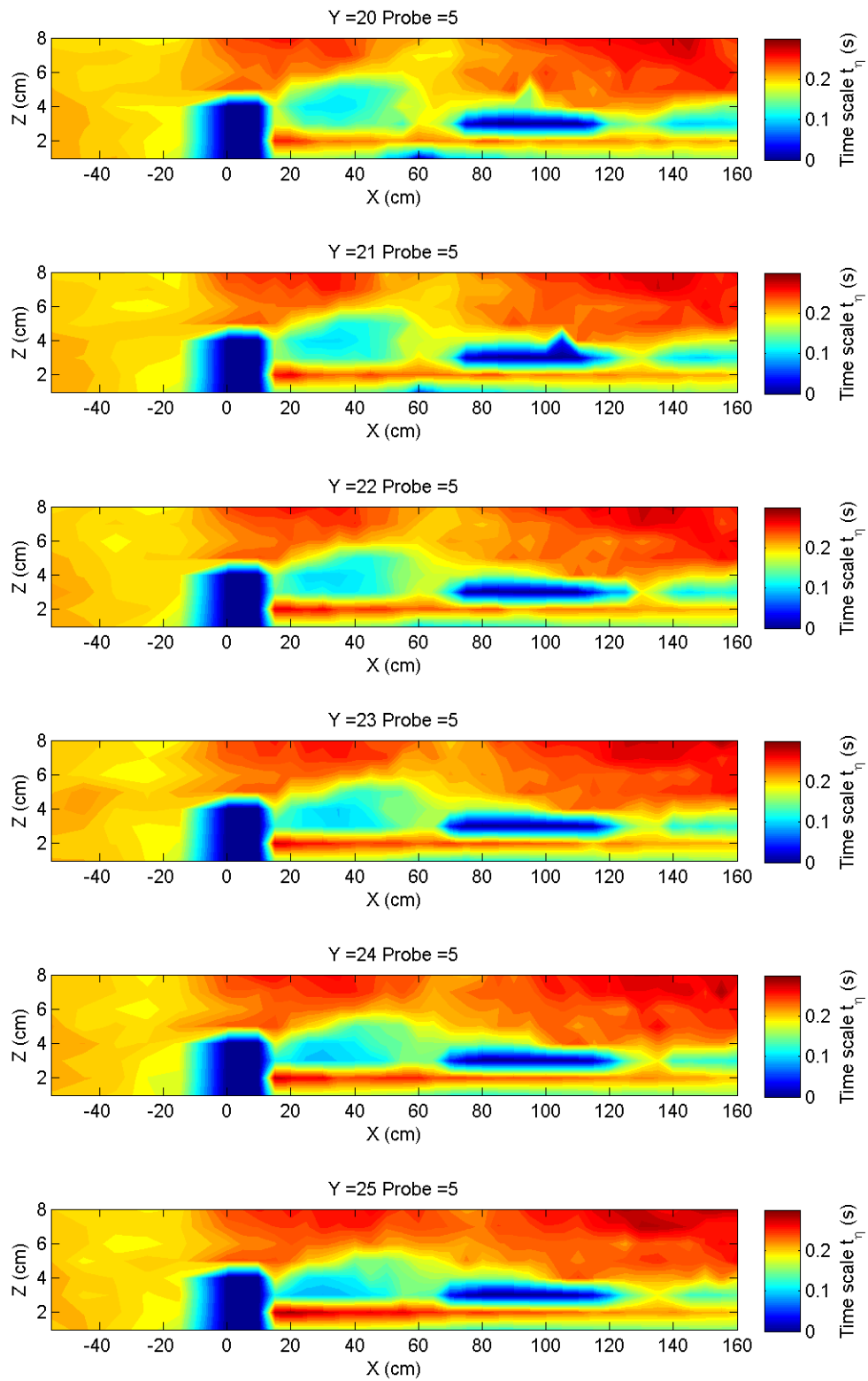


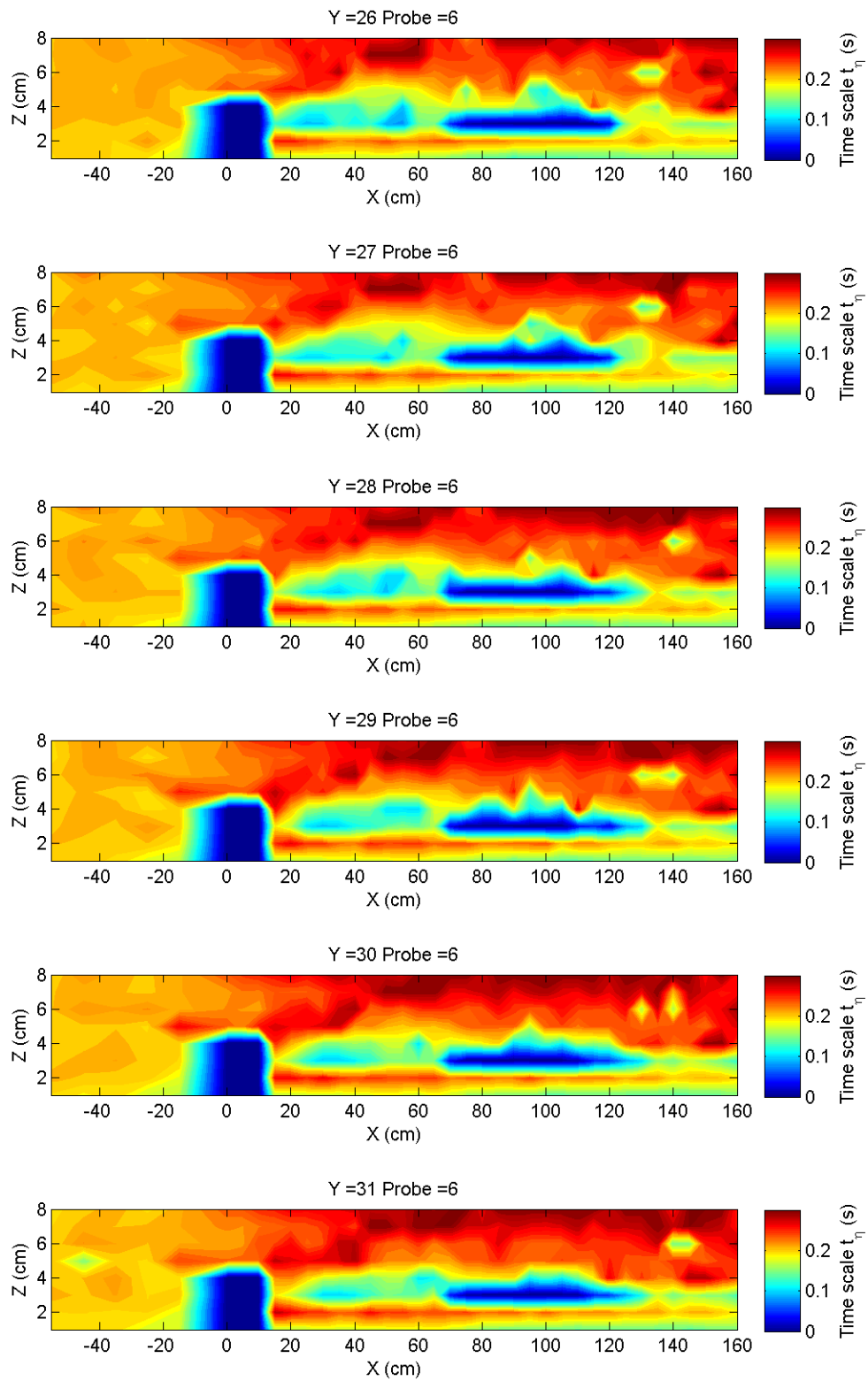


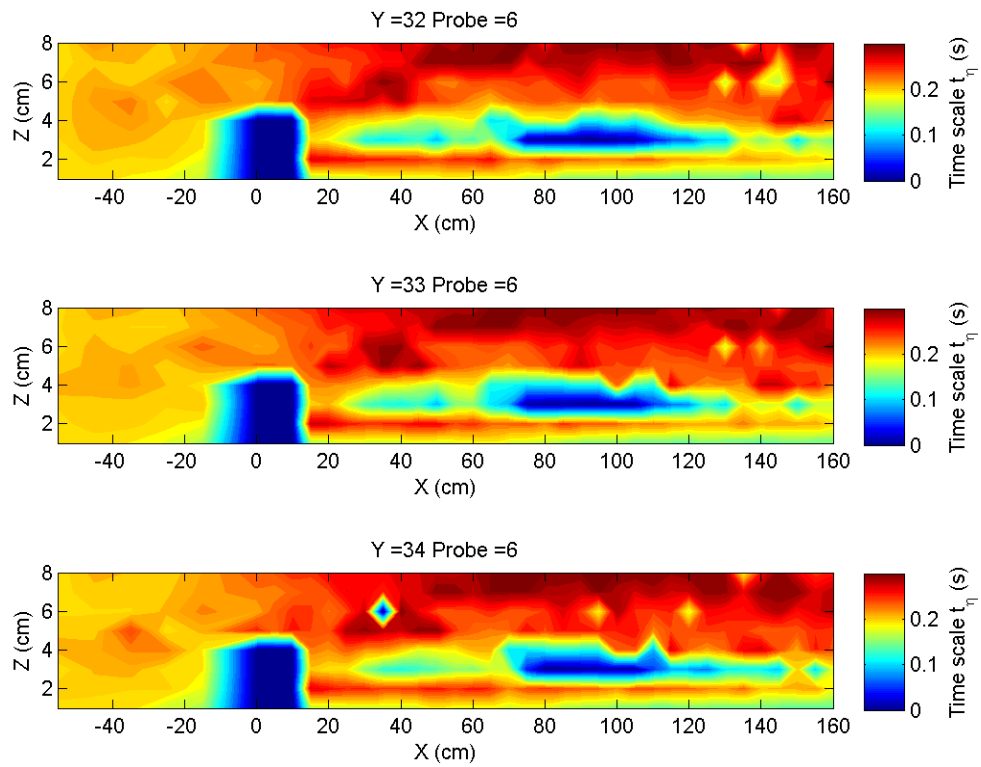






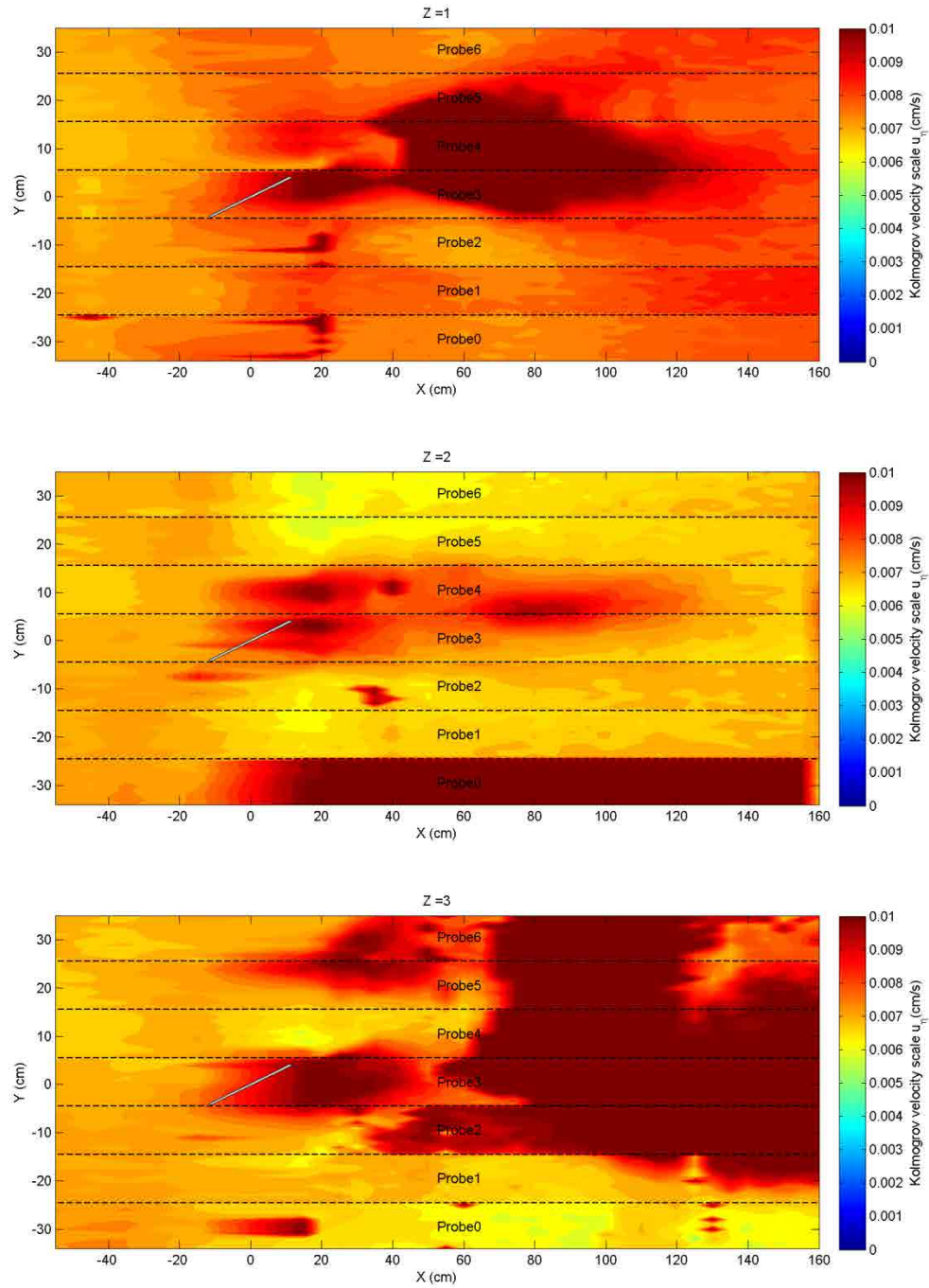


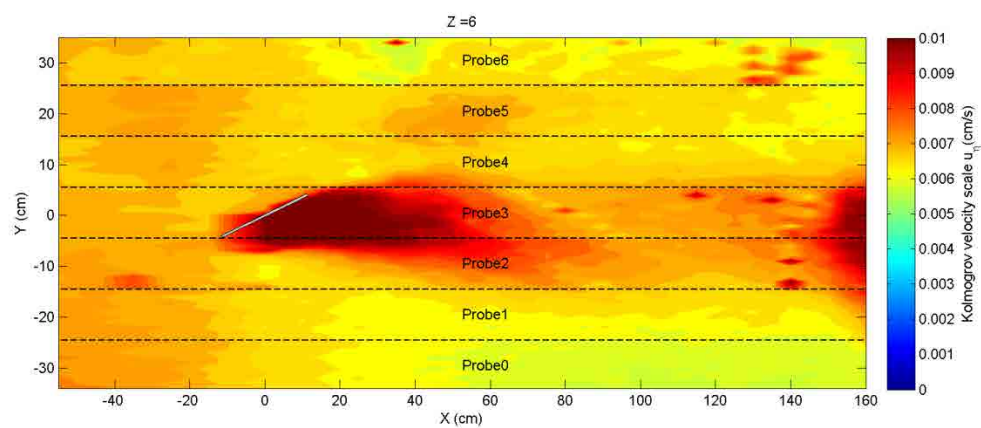
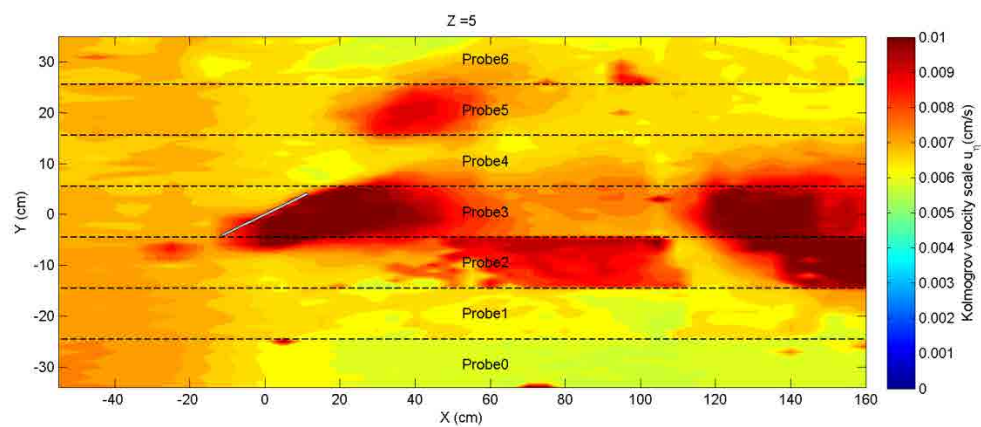
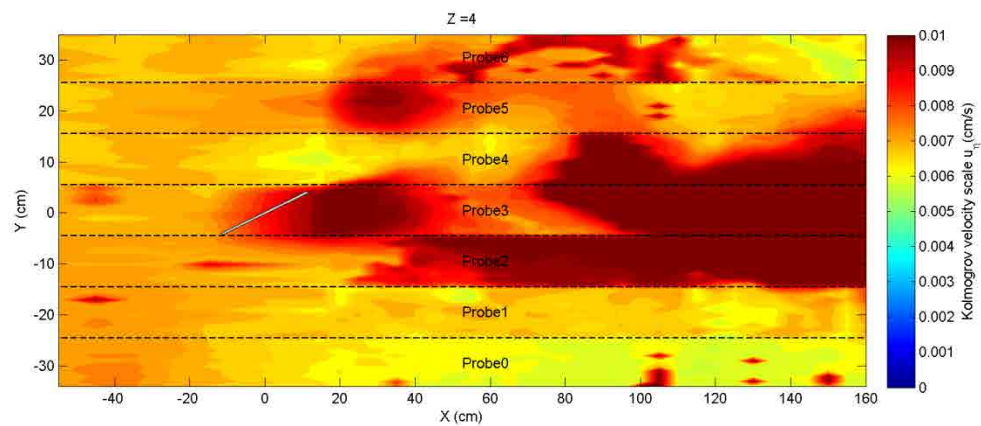


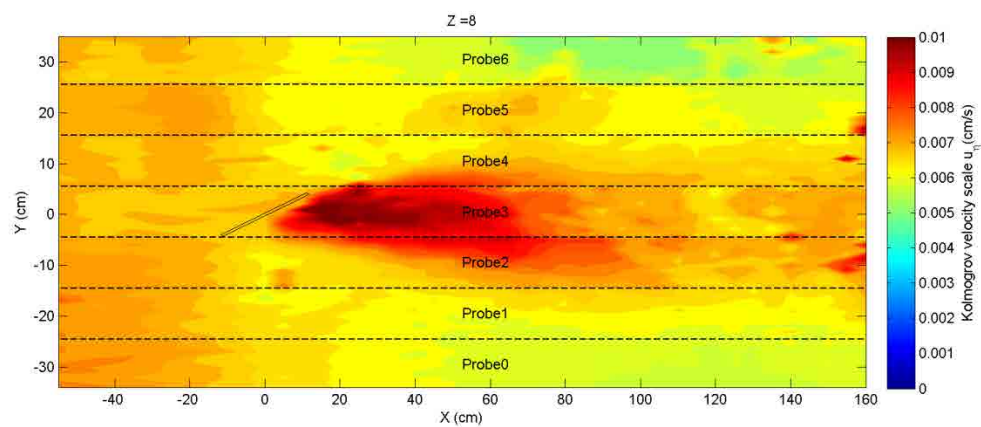
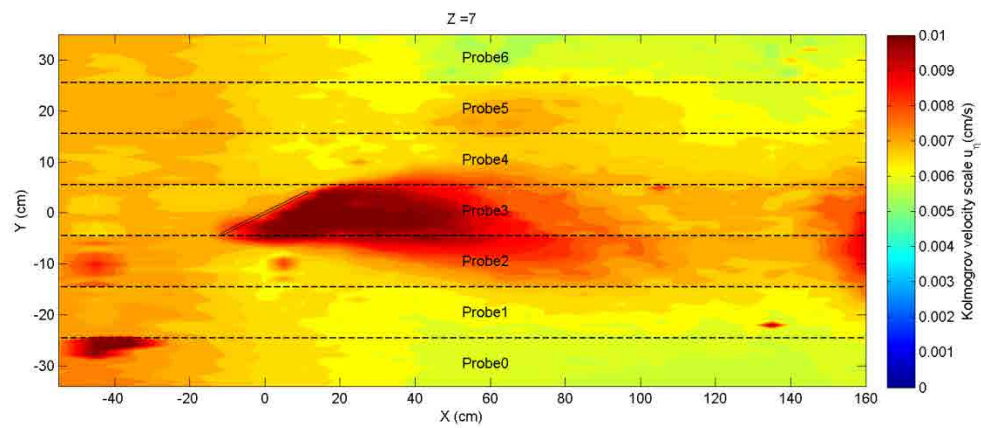


### 3. Kolmogorov Velocity Scale $u_\eta$

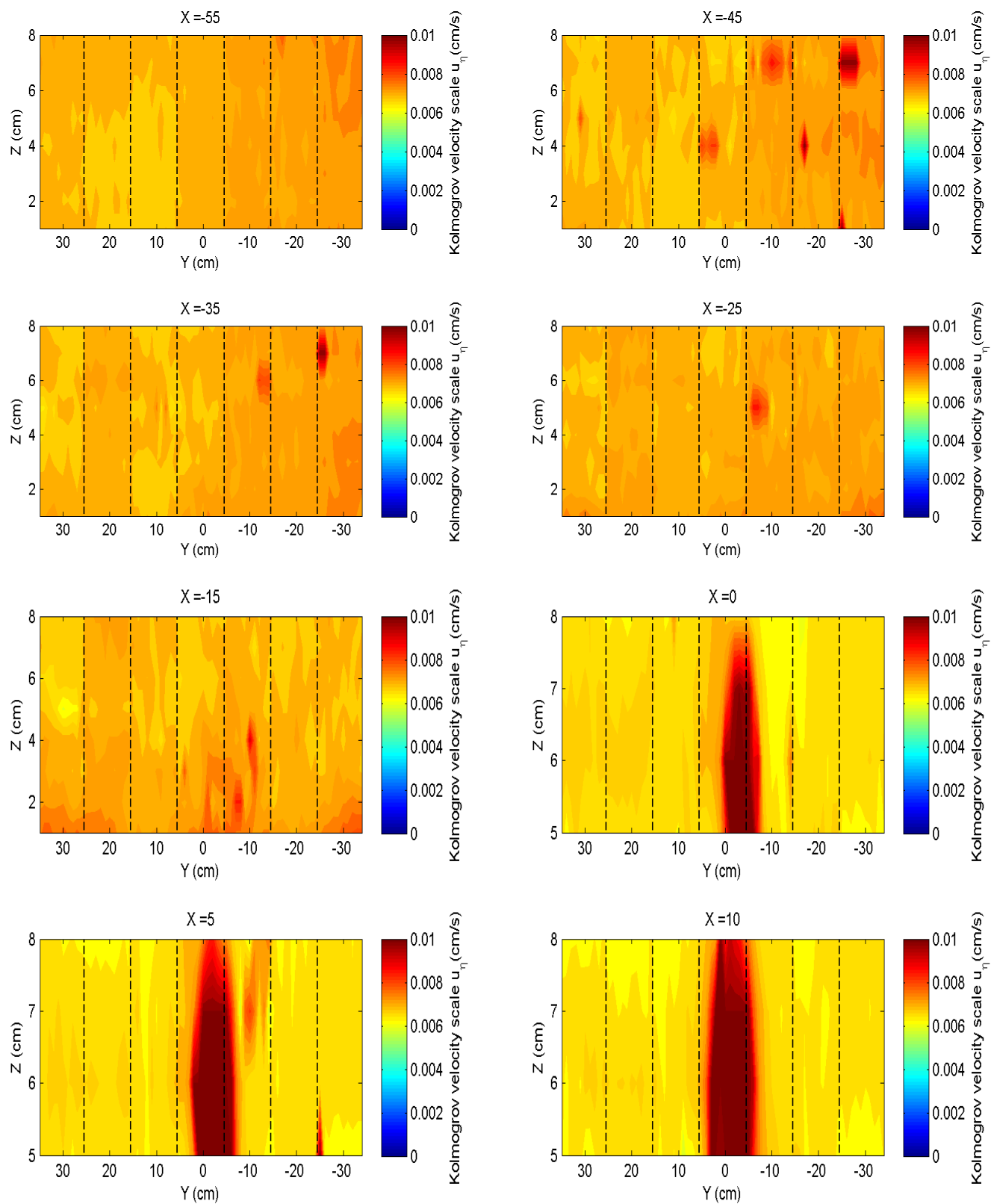
#### Kolmogorov Velocity Scale $u_\eta$ in x and y-Directions



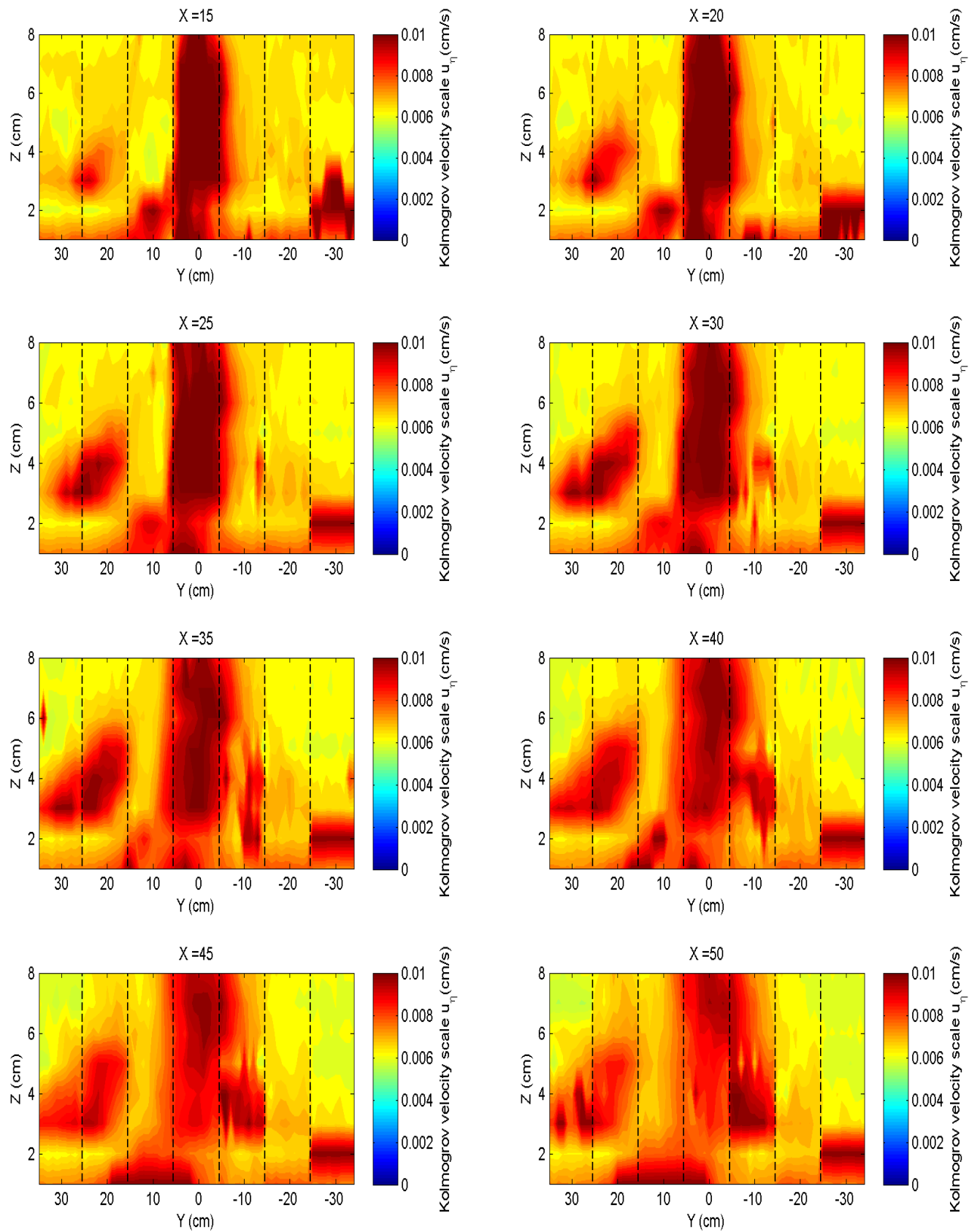




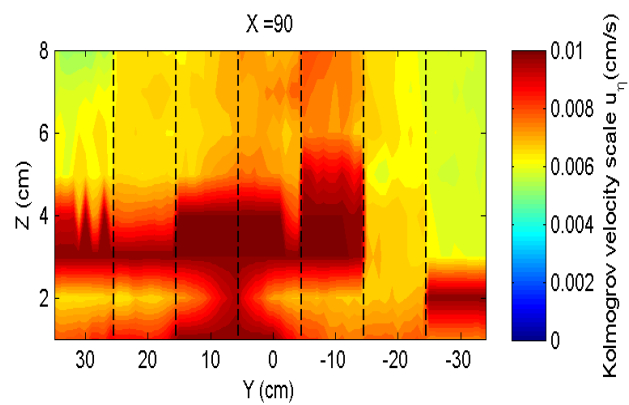
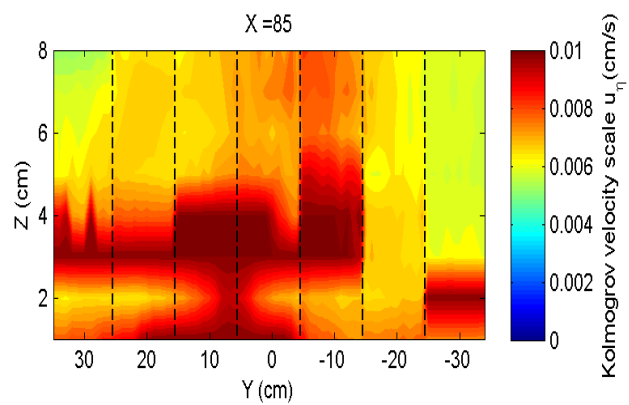
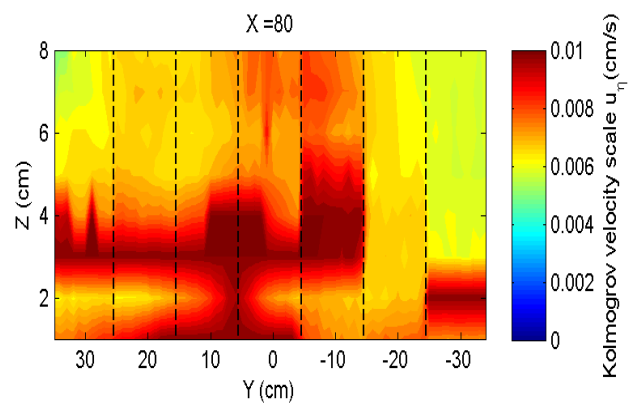
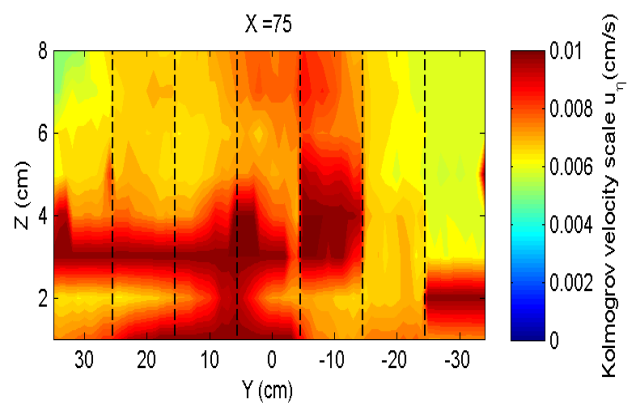
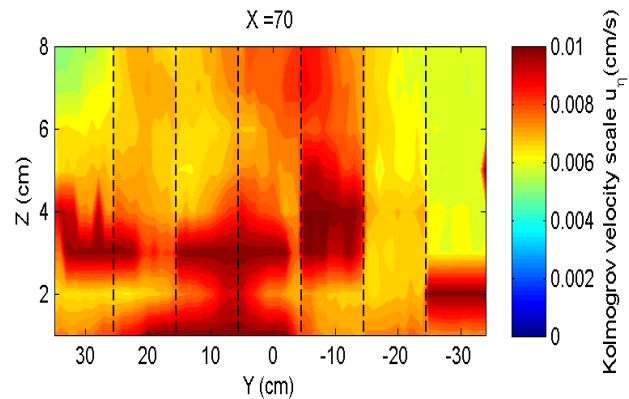
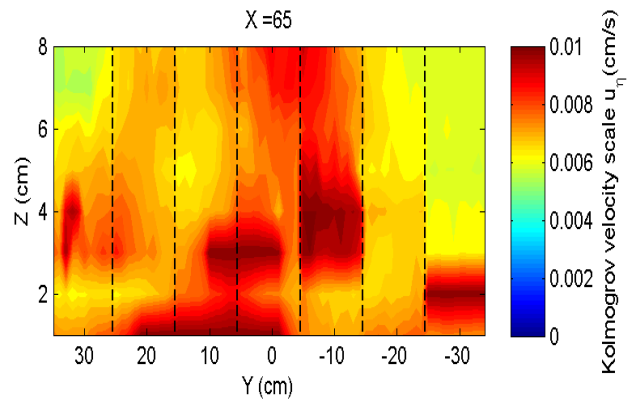
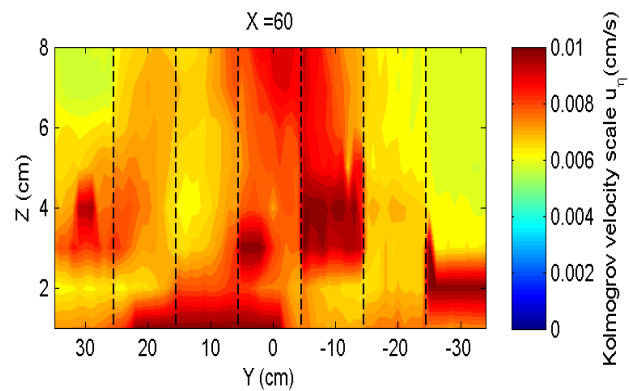
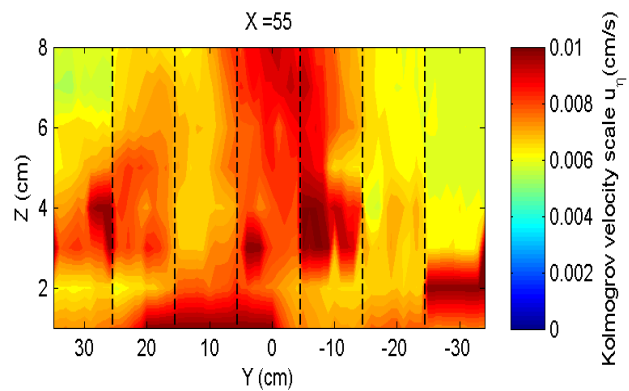
## Kolmogorov Velocity Scale $u_\eta$ in y and z-Directions

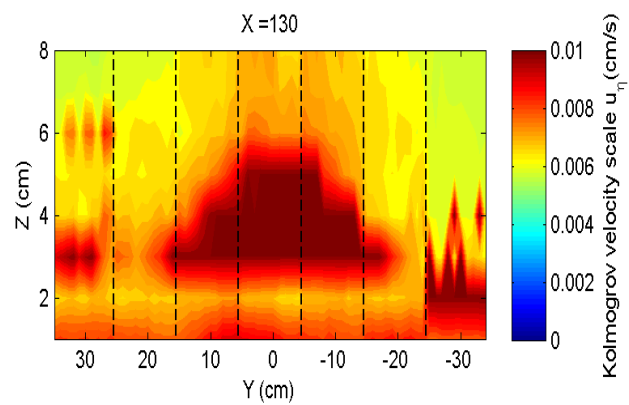
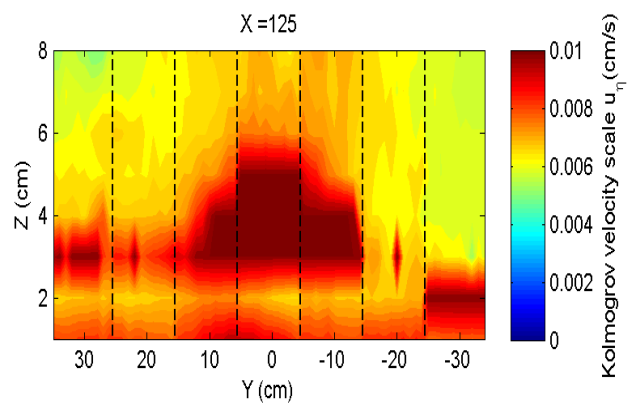
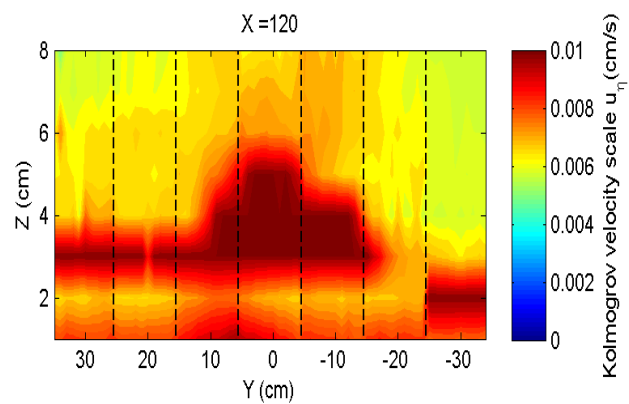
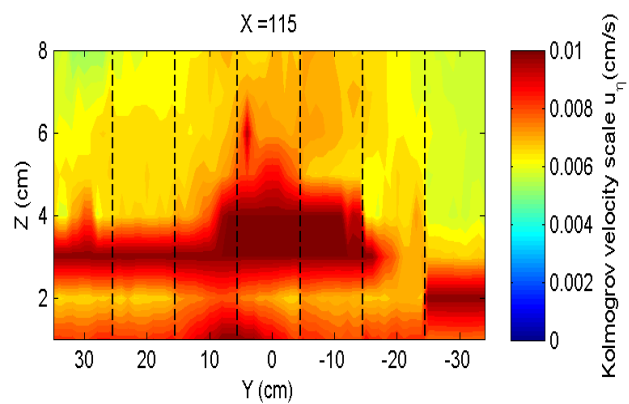
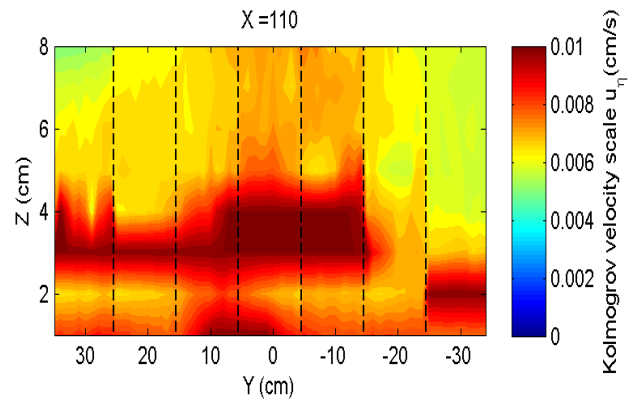
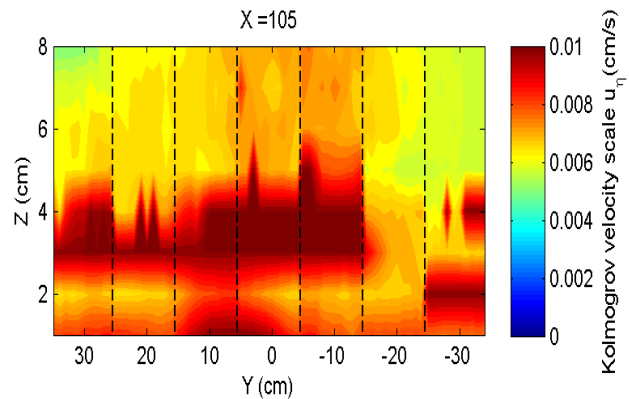
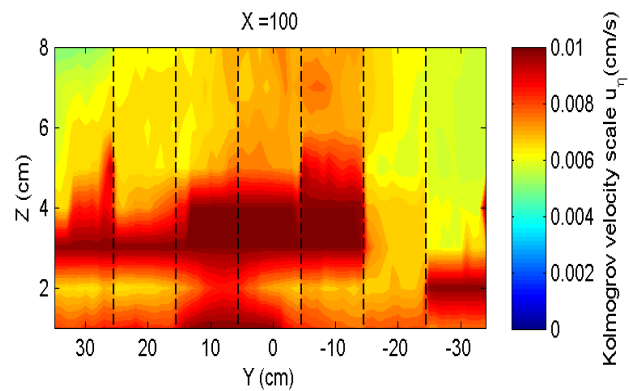
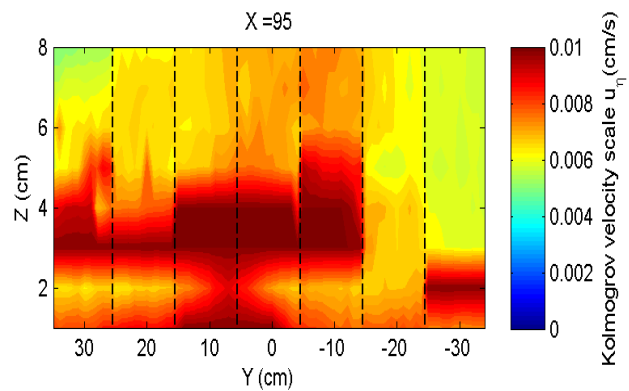


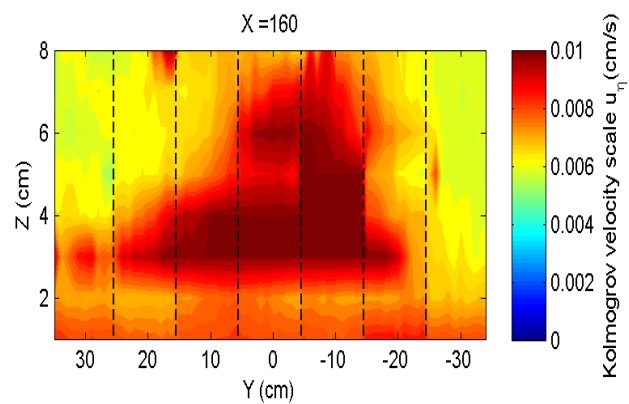
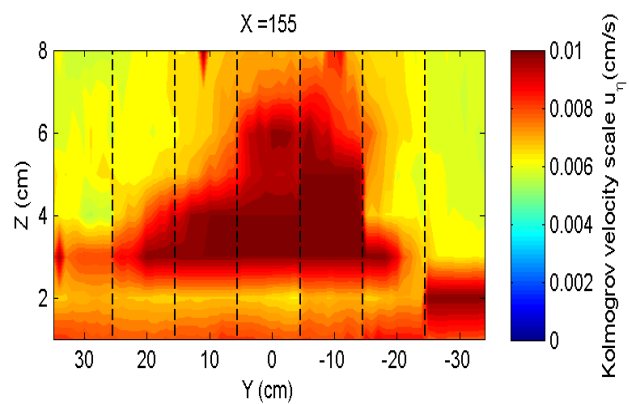
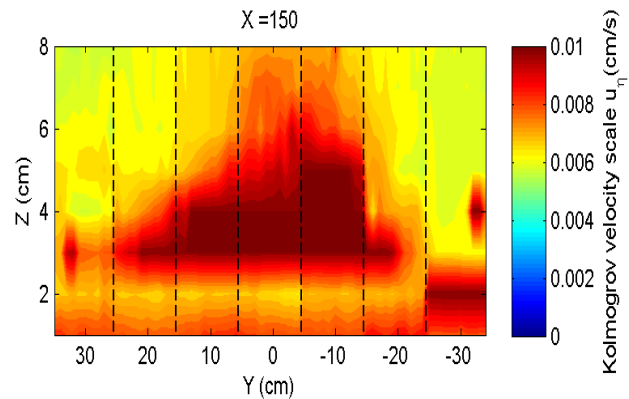
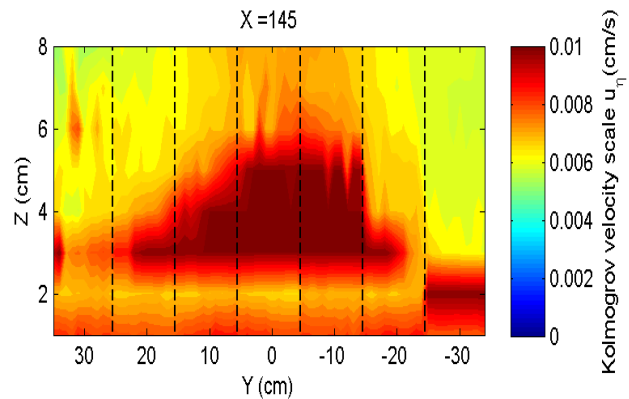
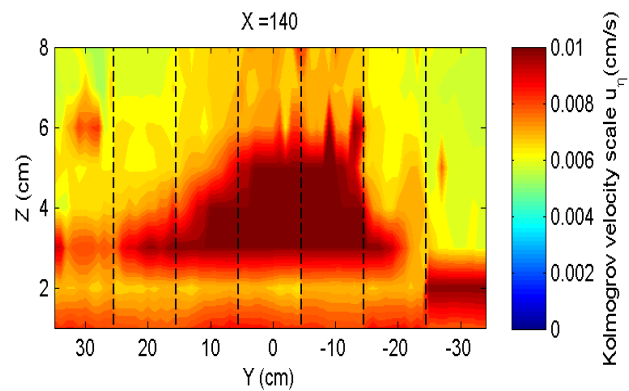
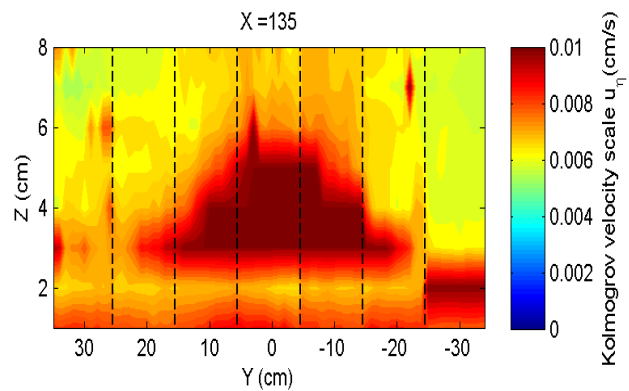












## Kolmogorov Velocity Scale $u_\eta$ in x and z-Directions

